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HOURLY TRANSPIRATION RATE ON CLEAR DAYS AS DETERMINED BY CYCLIC ENVIRONMENTAL FACTORS

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INTRODUCTION

The great differences exhibited by various plants in water requirement—i. e., in the water transpired in the production of a unit of dry matter—are of profound economic importance in the agricultural development of regions of limited rainfall, and an understanding of what gives rise to the greater efficiency which some plants possess in the use of water is highly desirable in the selection and breeding of plant strains adapted to dry-land agriculture. This problem has led the writers to undertake a series of transpiration measurements with a view to determining, so far as possible, the relative influence of various environmental factors on the transpiration of different plants. To this end simultaneous automatic records have been obtained of the solar-radiation intensity, the depression of the wet-bulb thermometer, the air temperature, the wind velocity, and the evaporation from a free-water surface. The present paper deals with the transpiration response of plants to these factors on clear days.

DESCRIPTION OF APPARATUS AND METHODS

MEASUREMENT OF TRANSPIRATION

The transpiration measurements described in this paper were carried out at Akron, Colo., in 1912, 1913, and 1914 (Pl. LIII). Transpiration was determined by weighing, four large automatic platform scales of a type already described (Briggs and Shantz, 1915)² being used in these measurements. The plants employed were those used in the water-

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² Bibliographic citations in parentheses refer to "Literature cited," p. 638-649.

requirement investigations, and were grown in the sealed pots already described (Briggs and Shantz, 1913, p. 9), which practically eliminate the direct loss of water from the soil. The pots contained about 115 kgm. of soil and were sufficiently large to enable the plants to make a normal growth, a factor of importance in transpiration measurements (Pl. LV, figs. 1-2). A part of the transpiration measurements were made within the screened inclosure (Pl. LIV, fig. 1) used in the water-requirement experiments to protect the plants from hail and wind storms. Other measurements were made outside the inclosure where the plants were freely exposed, with no protection whatever (Pl. LIV, fig. 2).

MEASUREMENT OF PHYSICAL FACTORS

SOLAR RADIATION.—The solar-radiation measurements were made automatically with a mechanical differential-telethermograph already described by one of the writers (Briggs, 1913). The instrument has two independent cylindrical bulbs and records only the difference in temperature of the two bulbs. When used for measuring radiation intensity, one bulb is blackened and surrounded by a spherical glass envelope (Pl. LIII). This is so exposed to the sun that the longer diameter of the bulb is normal to the sun's rays at midday. This bulb rises in temperature until the rate at which energy is lost is equal to the rate at which it is received. The other bulb follows the temperature of the air within the instrument shelter, through which the wind blows freely. The instrument was calibrated by comparison with an Abbot silver-disk pyrheliometer (Abbot, 1911). Such comparison shows that the difference in temperature, as measured by the telethermograph, is very nearly proportional to the intensity of the solar radiation falling on a blackened surface normal to the ray, as measured by the pyrheliometer. In other words, the scale is linear and the loss of energy conforms to Newton's law of cooling. While the telethermograph includes the sky radiation as well, the apparatus can be calibrated in terms of the solar radiation on bright days, since on clear days the ratio of sun to sky radiation appears to be fairly constant and the latter at the elevation of Akron (4,200 feet) is small compared with the direct radiation from the sun. A comparison of the telethermograph with the pyrheliometer, when the former is used for measuring radiation, is given in figure 1.

The radiation data given in this paper are expressed in terms of differential temperatures and the mean values are converted to calories per square centimeter per minute on a surface normal to the sun's rays.¹ The radiation is integrated for hourly periods so that zero radiation is not recorded until the hour following the hour interval during which the sun set, or preceding the hour interval during which the sun rose.

¹ The magnification of the differential sunshine instruments was not the same in 1912 and 1914. To convert to calories per square centimeter per minute multiply the differential temperatures in the 1912 observations by 0.2135; and in the 1914 observations by 0.028. In the 1914 observations the instruments were so adjusted as to give differential temperatures in degrees Fahrenheit.

WET-BULB DEPRESSION.—The measurement of the depression of the wet bulb was automatically carried on by means of a second differential telethermograph. One bulb was surrounded by muslin which was kept continuously saturated with water by means of a slowly-dripping Mariotte apparatus. In these measurements both bulbs were inside the instrument shelter and protected from solar radiation. The apparatus thus measured the depression of the wet bulb corresponding to the ventilation afforded by the wind through the shelter, which was similar to that to which the plants were subjected.

EVAPORATION.—In measuring the evaporation a shallow copper tank 91.3 cm. (3 feet) in diameter and 2.5 cm. deep was used, being mounted on the platform of an automatic scale of the type used in the transpiration measurements. The tank was clamped to a heavy, flat, wooden base,

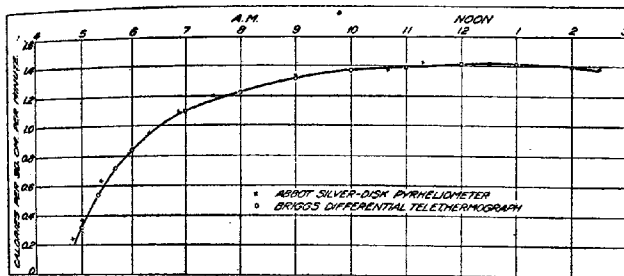


FIG. 1.—Curve showing the comparison of the readings of the differential telethermograph with those of Abbot's silver-disk pyrheliometer.

which was supported on leveling legs about 3 feet above the scale platform (Pl. LV, fig. 3). The inside of the tank was blackened with a mixture of lampblack in "bronzing liquid." The depth of the water in the tank was maintained at approximately 1 cm. by means of a Mariotte apparatus supported from the scale platform and located on the north side of the tank, so that its shadow did not fall on the tank.

AIR TEMPERATURE.—The air temperature was measured by a thermograph calibrated with mercurial thermometers and exposed in a standard shelter of the Weather Bureau pattern.

WIND VELOCITY.—The wind velocity was measured automatically by an anemometer of the Weather Bureau pattern, located 3 feet above the ground. In the 1914 measurements these measurements were supplemented by a special instrument recording each one-twentieth of a mile.

TRANSPIRATION RATE ON CLEAR DAYS IN RELATION TO PHYSICAL FACTORS

The transpiration graph for a single pot of plants for a single day usually shows slight irregularities. In order, therefore, to determine whether such departures are normal or accidental, it is necessary to combine

the transpiration graphs for a number of clear days sufficient to eliminate or minimize the accidental features. In the same manner a composite graph for the corresponding days can be prepared for each of the cyclic environmental factors—radiation, temperature, and wet-bulb depression. The evaporation data have also been combined in the same way. This procedure is not adapted to factors which are essentially noncyclic in character. Wind velocity, for example, is essentially cyclic in some regions and noncyclic in others. While the wind at Akron gives evidence of a daily periodicity, the cyclic character is not sufficiently developed to give the composite graph much weight. The discussion is not, however, limited to the composite values, the hourly values of the transpiration and of each environmental factor being given in the tables for each day considered.

WHEAT

The data obtained for the transpiration of wheat (*Triticum* spp.) on clear days in 1912 are given in Table I, and the environmental data for the corresponding period, including solar radiation, air temperature, and wind velocity in Tables II, III, and IV, respectively.

TABLE I.—Transpiration rate (in grams per hour) of wheat, at Akron, Colo., during June and July, 1912

Variety.	Balance No.	Date.	Hour ending—												P. M.											
			A. M.												Noon.											
			1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
Turkey.	B	June 25	6	6	6	8	10	20	80	140	180	220	240	240	240	240	210	270	240	220	180	94	10	12	12	10
	Do.	26	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	
	B	27	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	
	B	28	10	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	
	Do.	29	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	
	Do.	30	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	
Average for Turkey.	B	July 5	7	14	4	4	4	40	60	130	150	170	180	180	180	170	170	140	140	100	100	40	10	20	20	
	Do.	6	10	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	100	100	40	10	20	20	
	Do.	11	30	16	12	4	4	4	4	4	4	4	4	4	4	4	4	4	4	200	200	100	20	20	20	
	Do.	12	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	200	200	100	20	20	20	
	Do.	13	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	200	200	100	20	20	20	
	Do.	14	30	16	12	4	4	4	4	4	4	4	4	4	4	4	4	4	4	200	200	100	20	20	20	
Average for Kubanka.	A	June 25	4	4	4	4	4	40	46	86	90	100	100	100	100	100	100	100	100	107	73.4	24.5	17.4	17.4	14.3	13.7
	Do.	26	4	4	4	4	4	40	46	86	90	100	100	100	100	100	100	100	100	107	73.4	24.5	17.4	17.4	14.3	13.7
	A	27	4	4	4	4	4	40	46	86	90	100	100	100	100	100	100	100	100	107	73.4	24.5	17.4	17.4	14.3	13.7
	Do.	28	4	4	4	4	4	40	46	86	90	100	100	100	100	100	100	100	100	107	73.4	24.5	17.4	17.4	14.3	13.7
	A	29	4	4	4	4	4	40	46	86	90	100	100	100	100	100	100	100	100	107	73.4	24.5	17.4	17.4	14.3	13.7
	Do.	30	4	4	4	4	4	40	46	86	90	100	100	100	100	100	100	100	100	107	73.4	24.5	17.4	17.4	14.3	13.7
Average for Kharkov.	A	July 5	4	4	4	4	4	40	32	50	60	70	80	80	80	80	70	70	50	30	180	110	10	10	10	10
	Do.	6	4	4	4	4	40	32	50	60	70	80	80	80	80	80	70	70	50	30	180	110	10	10	10	10
	A	7	4	4	4	4	4	40	32	50	60	70	80	80	80	80	70	70	50	30	180	110	10	10	10	10
	Do.	8	4	4	4	4	4	40	32	50	60	70	80	80	80	80	70	70	50	30	180	110	10	10	10	10
	Do.	9	4	4	4	4	4	40	32	50	60	70	80	80	80	80	70	70	50	30	180	110	10	10	10	10
	Do.	10	4	4	4	4	4	40	32	50	60	70	80	80	80	80	70	70	50	30	180	110	10	10	10	10
Average for Kubanka.	A	June 25	4.4	4.4	4.4	4.4	4.1	5	34.5	65.7	98.2	123	131	141	149	162.5	165	174	160	149	110.5	49.5	11.5	6.5	4.8	4.8
	Do.	26	4.4	4.4	4.4	4.4	4.1	5	34.5	65.7	98.2	123	131	141	149	162.5	165	174	160	149	110.5	49.5	11.5	6.5	4.8	4.8
	C	27	4	4	4	4	4	40	46	86	90	100	100	100	100	100	100	100	100	107	73.4	24.5	17.4	17.4	14.3	13.7
	Do.	28	16	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	
	C	29	4	4	4	4	4	40	46	86	90	100	100	100	100	100	100	100	100	107	73.4	24.5	17.4	17.4	14.3	13.7
	Do.	30	4	4	4	4	4	40	46	86	90	100	100	100	100	100	100	100	100	107	73.4	24.5	17.4	17.4	14.3	13.7
Average for Kharkov.	C	June 25	18	12	8	6	12	8	12	80	150	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200
	Do.	26	16	12	8	6	12	8	12	80	150	200	200	200	200	200	200	200	200	200	200	200	200	200	200	
	C	27	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	
	Do.	28	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	
	D	29	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	
	Do.	30	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	
Average for Kharkov.	D	July 5	9.5	8.2	7.2	6.8	12.3	35.7	108.3	193.4	217	217	215	208	202	302	300	309	253	183	84	26	15.3	18	27.8	15
	Do.	6	8.8	7.1	6.7	6.7	8.7	34.3	85.5	142.7	170.2	193.3	199	209.5	221.4	238.1	236.7	192.3	150	67.3	20	12.7	12.8	11.5	10.6	
	A	7	4	3	3	3	4	14	36	62	71	81	84	88	93	97	100	95	81	63	28	8	5	5	4	
	Do.	8	4	3	3	3	4	14	36	62	71	81	84	88	93	97	100	95	81	63	28	8	5	5	4	
	A	9	4	3	3	3	4	14	36	62	71	81	84	88	93	97	100	95	81	63	28	8	5	5	4	
	Do.	10	4	3	3	3	4	14	36	62	71	81	84	88	93	97	100	95	81	63	28	8	5	5	4	

TABLE II.—*Howe's solar radiation intensity (observed differential temperatures) during wheat transpiration period, at Akron, Colo., during June and July, 1912*

Date.	Weight.	Hour ending—																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																												
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June 20.....	1	5	7	13	16	19	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21</

TABLE III.—Hourly temperatures (in degrees Fahrenheit) during wheat transpiration period, at Akron, Colo., during June and July, 1912

[illegible]

TABLE IV.—Wind velocity in miles per hour during wheat transpiration period at Akron, Colo., during June and July, 1912

Date.	Weight.	Hour ending—																								
		A. M.									Noon.			P. M.												
		1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	
June 20.....	1	1.0	1.0	2.0	3.0	3.0	3.0	5	4	3	3.8	3	2.7	2.7	3.1	3.4	2.4	1.5	7.6	2	1	1.5	0.8	0.3		
21.....	2	3.0	3.0	3.0	4.0	5.0	4	7.2	6.5	5.8	4.2	2.0	1.0	1.5	1.5	1.3	2.3	3.0	3.0	4.1	1.5	1.5	1.3	2	1.2	
22.....	3	3.0	6.5	2.0	4.0	5.0	4	7.2	6.5	5.8	4.2	2.0	1.0	1.5	1.5	1.3	2.3	3.0	3.0	4.1	2.0	1.5	1.5	1	1.2	
23.....	4	3.0	6.5	2.0	4.0	5.0	4	7.2	6.5	5.8	4.2	2.0	1.0	1.5	1.5	1.3	2.3	3.0	3.0	4.1	2.0	1.5	1.5	1	1.2	
24.....	5	3.0	6.5	2.0	4.0	5.0	4	7.2	6.5	5.8	4.2	2.0	1.0	1.5	1.5	1.3	2.3	3.0	3.0	4.1	2.0	1.5	1.5	1	1.2	
25.....	6	3.0	6.5	2.0	4.0	5.0	4	7.2	6.5	5.8	4.2	2.0	1.0	1.5	1.5	1.3	2.3	3.0	3.0	4.1	2.0	1.5	1.5	1	1.2	
26.....	7	3.0	6.5	2.0	4.0	5.0	4	7.2	6.5	5.8	4.2	2.0	1.0	1.5	1.5	1.3	2.3	3.0	3.0	4.1	2.0	1.5	1.5	1	1.2	
27.....	8	3.0	6.5	2.0	4.0	5.0	4	7.2	6.5	5.8	4.2	2.0	1.0	1.5	1.5	1.3	2.3	3.0	3.0	4.1	2.0	1.5	1.5	1	1.2	
28.....	9	1.0	2.5	3.0	3.5	3.0	5.0	5	4.3	4.5	4.6	3.2	3.0	2.0	2.0	2.0	6.2	6.7	6.0	4.0	1.5	1.5	1.0	3.0	4.0	
29.....	10	1.0	1.0	1.0	1.5	1.5	1.5	4.2	6.0	3.8	3.3	2.8	3.0	4.0	4.3	4.0	4.5	7.0	10.5	1.0	7.0	4.0	4.0	5.0	2.0	
July 1.....	11	1.0	1.0	1.0	1.5	1.5	1.5	4.2	6.0	3.8	3.3	2.8	3.0	4.0	4.3	4.0	4.5	7.0	10.5	1.0	7.0	4.0	4.0	5.0	2.0	
2.....	12	1.0	1.0	1.0	1.5	1.5	1.5	4.2	6.0	3.8	3.3	2.8	3.0	4.0	4.3	4.0	4.5	7.0	10.5	1.0	7.0	4.0	4.0	5.0	2.0	
3.....	13	1.0	1.0	1.0	1.5	1.5	1.5	4.2	6.0	3.8	3.3	2.8	3.0	4.0	4.3	4.0	4.5	7.0	10.5	1.0	7.0	4.0	4.0	5.0	2.0	
4.....	14	1.0	1.0	1.0	1.5	1.5	1.5	4.2	6.0	3.8	3.3	2.8	3.0	4.0	4.3	4.0	4.5	7.0	10.5	1.0	7.0	4.0	4.0	5.0	2.0	
5.....	15	1.0	1.0	1.0	1.5	1.5	1.5	4.2	6.0	3.8	3.3	2.8	3.0	4.0	4.3	4.0	4.5	7.0	10.5	1.0	7.0	4.0	4.0	5.0	2.0	
6.....	16	1.0	1.0	1.0	1.5	1.5	1.5	4.2	6.0	3.8	3.3	2.8	3.0	4.0	4.3	4.0	4.5	7.0	10.5	1.0	7.0	4.0	4.0	5.0	2.0	
7.....	17	1.0	1.0	1.0	1.5	1.5	1.5	4.2	6.0	3.8	3.3	2.8	3.0	4.0	4.3	4.0	4.5	7.0	10.5	1.0	7.0	4.0	4.0	5.0	2.0	
8.....	18	1.0	1.0	1.0	1.5	1.5	1.5	4.2	6.0	3.8	3.3	2.8	3.0	4.0	4.3	4.0	4.5	7.0	10.5	1.0	7.0	4.0	4.0	5.0	2.0	
9.....	19	1.0	1.0	1.0	1.5	1.5	1.5	4.2	6.0	3.8	3.3	2.8	3.0	4.0	4.3	4.0	4.5	7.0	10.5	1.0	7.0	4.0	4.0	5.0	2.0	
10.....	20	1.0	1.0	1.0	1.5	1.5	1.5	4.2	6.0	3.8	3.3	2.8	3.0	4.0	4.3	4.0	4.5	7.0	10.5	1.0	7.0	4.0	4.0	5.0	2.0	
11.....	21	1.0	1.0	1.0	1.5	1.5	1.5	4.2	6.0	3.8	3.3	2.8	3.0	4.0	4.3	4.0	4.5	7.0	10.5	1.0	7.0	4.0	4.0	5.0	2.0	
Average.....		3.3	3.7	3.0	3.1	3.6	4.1	5.7	7.5	7.0	6.7	5.9	5.3	5.1	5.3	5.2	5.7	5.7	5.3	5.3	2.8	2.8	1.6	1.8	2.5	

The mean values are plotted in figure 2. It should be recalled that all transpiration measurements in 1912 were made in the hail-screen inclosure (Pl. LIV, fig. 1). The radiation measurements were likewise made under this screen, which reduced the radiation about 20 per cent (Briggs and Shantz, 1914, p. 3). It should also be borne in mind that during the year of 1912 the solar radiation outside the inclosure was about 20 per cent lower than normal (Briggs and Shantz, 1914, p. 54).

The mean solar radiation shown in the first curve of figure 2 is relatively symmetrical, as would be expected if clear or only slightly cloudy days

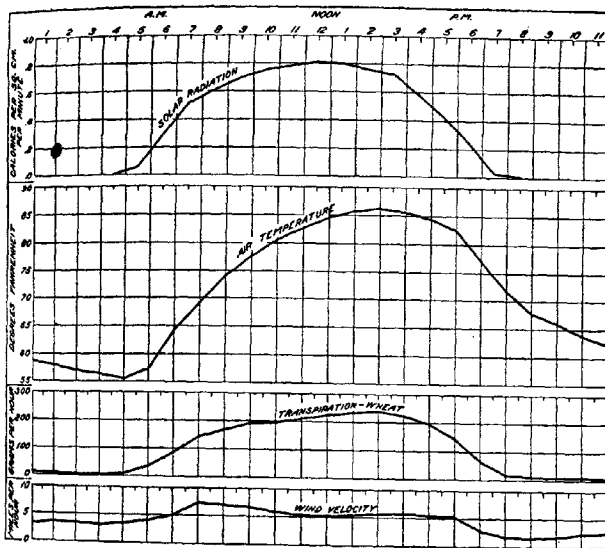


FIG. 2.—Composite transpiration graph of wheat and environmental graphs for corresponding period.

are chosen. The maximum radiation is reached at 12 o'clock, noon, and amounts at that time to only 0.80 calories per square centimeter per minute. The gradient is steep during the early morning and late afternoon, but there is little change in the radiation intensity during the midday hours.

The second graph in figure 2 gives the hourly air temperature in degrees Fahrenheit. The temperature reaches its minimum, 55° F., between 4 and 5 a. m., and its maximum, 86° F., between 2 and 3 in the afternoon. The average temperature from noon to midnight is much higher than from midnight to noon.

The transpiration is recorded in grams per hour. It will be seen from the graph in figure 3 that the transpiration during the night is almost negligible. A marked increase is recorded at 6 o'clock in the morning.

The maximum of 238 gm. per hour is reached about 2.30 p. m., after which the transpiration falls rapidly and acquires the average night rate soon after sunset. There is an indication from the flattening of the curve after 8 o'clock a. m. that from this point on to the maximum the plant modifies its transpiration coefficient.¹ This may be in part due to the closing of the stomata during this period and in part to the lowering of the vapor pressure of the sap of the mesophyll cells resulting from an increase in concentration.

At the bottom of figure 2 is shown the mean wind velocity for each hour of the day. It will be seen that the maximum rate is reached about 7.30 a. m. There is a gradual falling off until about noon, after which the wind velocity remains constant until 5.30 p. m. During the night the rate is somewhat lower.

The transpiration graph of wheat in figure 2 is a composite based upon transpiration measurements of Kharkov and Turkey winter wheats, both

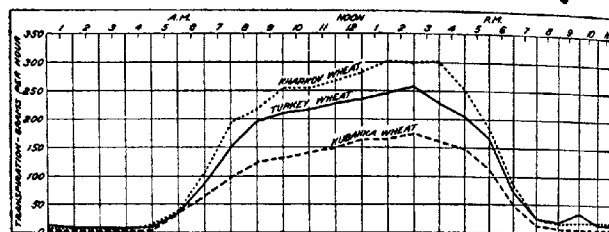


FIG. 3.—Composite transpiration graphs for the three varieties of wheat from which the composite graph of figure 2 was obtained.

being varieties of *Triticum aestivum*, and of one hard spring wheat, Kubanka, a variety of *Triticum durum*.² The transpiration graphs for each variety, based upon the data given in Table I, are presented in figure 3. It will be noted that the graphs have essentially the same form and that each graph after 9 a. m. shows a falling off in the transpiration rate below that indicated by the slope during the early morning hours.

OATS³

The data covering the transpiration measurements of oats (*Avena sativa*) on clear days are presented in Table V and the environmental measurements for the corresponding period in Tables VI to IX. The

¹ If a plant in its transpiration response to its environment acted as a free physical system, it would be possible to express the transpiration rate in the form of an equation involving the intensity of each of the individual environmental factors. If the relative part played by each factor in determining transpiration were known, then simply by determining the transpiration rate corresponding to some given environment, the transpiration rate for any other environment could be computed. The ratio of the transpiration rate to the environmental intensity would then be defined as the *transpiration coefficient* of the particular plant under observation.

² Kharkov, C. I. (Cereal Investigations) No. 1583; Turkey, C. I. No. 1575; and Kubanka, C. I. No. 144.

³ Swedish Select, C. I. No. 134.

mean hourly values for each environmental factor and for the transpiration are plotted in figure 4. The graphs for the physical factors represent in each case the mean hourly values for eight clear days. The

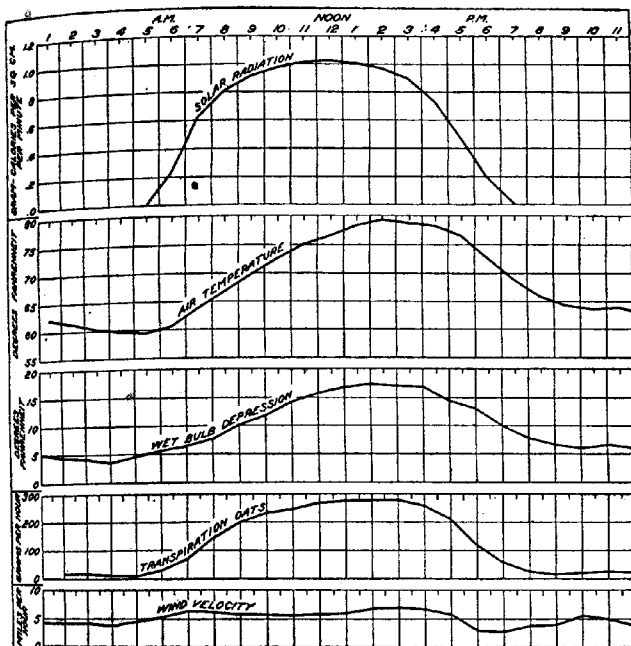


FIG. 4.—Composite transpiration graph for oats, with environmental graphs for corresponding period.

transpiration measurements were made in duplicate, using two pots of oats of the same variety, each pot being mounted independently on an automatic balance. The hourly transpiration values plotted in figure 4, therefore, represent the mean of 16 determinations.

TABLE V.—Transpiration rate (in grams per hour) of oats at Akron, Colo., from August 4 to 18, 1912

Date.	Bal- ance No.	Hour ending—																							
		A. M.											P. M.												
		1	2	3	4	5	6	7	8	9	10	11	Noon.	1	2	3	4	5	6	7	8	9	10	11	12
Aug. 4.....	32-2	4	8	8	8	12	20	50	134	276	314	374	406	400	380	300	220	144	62	28	14	10	24	28	58
5.....	36	4	4	4	4	4	12	36	130	272	310	362	394	464	324	260	214	150	62	32	12	10	20	20	50
6.....	6	14.6	6	6	8.4	22	66	144	146	168	202	190	210	180	160	202	168	104	126	42	16	14	18	10	12
7.....	6	8	8	8	8	10	10	10	134	140	212	192	180	164	166	224	248	170	134	48	18	16	14	10	18
8.....	8	8	8	8	8	10	10	10	134	140	212	192	180	164	166	224	248	170	134	48	18	16	14	10	18
9.....	8	8	8	8	8	10	10	10	134	140	212	192	180	164	166	224	248	170	134	48	18	16	14	10	18
10.....	8	8	8	8	8	10	10	10	134	140	212	192	180	164	166	224	248	170	134	48	18	16	14	10	18
11.....	46	22	48	4	4	6	6	6	144	200	224	216	280	294	284	300	264	216	174	126	14	28	20	24	32
12.....	44	34	34	34	34	48	48	48	144	200	224	216	280	294	284	300	264	216	174	126	14	28	20	24	32
13.....	10	26	34	34	34	48	48	48	144	200	224	216	280	294	284	300	264	216	174	126	14	28	20	24	32
14.....	10	26	34	34	34	48	48	48	144	200	224	216	280	294	284	300	264	216	174	126	14	28	20	24	32
15.....	10	26	34	34	34	48	48	48	144	200	224	216	280	294	284	300	264	216	174	126	14	28	20	24	32
16.....	4	4	4	4	4	8	8	8	144	180	202	188	204	200	210	208	198	174	124	48	20	16	3	4	4
17.....	10	26	34	34	34	48	48	48	144	176	190	194	244	214	216	186	168	168	168	166	44	16	12	26	14
18.....	10	26	34	34	34	48	48	48	144	176	190	194	244	214	216	186	168	168	168	166	44	16	12	26	14
Average.	17.5	17.3	17.3	12.5	12.1	20.8	66.0	66.0	140	193	227.7	242	263	265.1	269.1	271	253.6	268.7	146.3	53.6	19.6	10.6	10.5	10.8	19.6
Percentage of maxi- mum.....	6	6	6	5	4	8	24	24	52	72	84	89	97	98	99	100	94	77	54	20	7	6	6	7	7

TABLE VI.—Hourly solar radiation intensity (observed differential temperature) during oats transpiration period, at Akron, Colo., from August 4 to 18, 1912

Date.	Hour ending—												
	A. M.						P. M.						
	6	7	8	9	10	11	Noon.	1	2	3	4	5	6
Aug. 4.....			22.5	27.5	29	30	30	30	28.5	27	23	7	2
5.....		17	22	26.5	27	28	29	29	28.5	26	26	17	3
6.....		20	25	28	29.5	30.5	31	30	28.5	26	26	18	3.5
7.....		17	23	27	29	30.5	31	30	29	24	19.5	13	2
8.....		4	20	25	27	28.5	27	28.5	28.5	26.5	26.5	13	2
9.....		12	22	27	27	28	27	28	27.5	26	26	17	2
10.....		7	23	27	28	29	30	30.5	30.5	30	29	17	2.5
11.....		16	22	27	29	30	31	30.5	30	30	28	17	2
12.....		7	23	27	29	30	31	31.5	31	27	21.5	17	2
13.....		16	25	28	29.5	31	31.5	31	30	27	21.5	17	2
14.....		7	23	27	29	30	30.5	30.5	30	27	21.5	17	2
15.....		16	25	28	29.5	31	31.5	31	30	27	21.5	17	2
16.....		7	23	27	29	30	30.5	30.5	30	27	21.5	17	2
17.....		16	25	28	29.5	31	31.5	31	30	27	21.5	17	2
18.....		7	23	27	29	30	30.5	30.5	30	27	21.5	17	2
19.....		16	25	28	29.5	31	31.5	31	30	27	21.5	17	2
20.....		7	23	27	29	30	30.5	30.5	30	27	21.5	17	2
21.....		16	25	28	29.5	31	31.5	31	30	27	21.5	17	2
22.....		7	23	27	29	30	30.5	30.5	30	27	21.5	17	2
23.....		16	25	28	29.5	31	31.5	31	30	27	21.5	17	2
24.....		7	23	27	29	30	30.5	30.5	30	27	21.5	17	2
25.....		16	25	28	29.5	31	31.5	31	30	27	21.5	17	2
26.....		7	23	27	29	30	30.5	30.5	30	27	21.5	17	2
27.....		16	25	28	29.5	31	31.5	31	30	27	21.5	17	2
28.....		7	23	27	29	30	30.5	30.5	30	27	21.5	17	2
29.....		16	25	28	29.5	31	31.5	31	30	27	21.5	17	2
30.....		7	23	27	29	30	30.5	30.5	30	27	21.5	17	2
31.....		16	25	28	29.5	31	31.5	31	30	27	21.5	17	2
Average.....	6.6	18.4	23.7	26.9	27.5	29.8	30.2	29.7	28.7	26.7	21.5	13.8	5.6
Calories per sq. cm. per minute.....	.22	.62	.79	.90	.91	1.00	1.01	1.00	.96	.89	.72	.46	.19
Percentage of maximum.....	22	61	78	89	91	99	100	98	95	88	71	46	19

TABLE VII.—Hourly temperatures (in degrees Fahrenheit) during oats transpiration period, at Akron, Colo., from August 4 to 18, 1912

Date.	Hour ending--											
	A. M.						P. M.					
	1	2	3	4	5	6	7	8	9	10	11	12
Aug. 4	61.5	61.5	61.5	61.8	62	62	64	67.5	70	74	78	80.6
5	63	60	61.5	61.5	62	62	64	67.5	70	74	78	80.6
6	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5
7	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5
8	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5
9	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5
10	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5
11	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5
12	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5
13	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5
14	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5
15	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5
16	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5
17	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5
18	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5
19	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5
20	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5
21	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5
22	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5
23	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5
24	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5
25	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5
Average	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5	61.5
Average in degrees centigrade	16.7	16.7	16.7	16.7	16.7	16.7	16.7	16.7	16.7	16.7	16.7	16.7
Percentage of maximum range	14	14	14	14	14	14	14	14	14	14	14	14

TABLE VIII.—Hourly wet-bulb depression (in degrees Fahrenheit) during oats transpiration period at Akron, Colo., from August 4 to 18, 1912

Date.	Hour ending—											
	A. M.						P. M.					
	1	2	3	4	5	6	7	8	9	10	11	12
Aug. 4.....	7	1	1	1	1.5	1.5	2	2	2	2	2	7
5.....	8	0	0	0	4.5	4.5	6.5	6.5	6.5	6.5	6.5	7
6.....	8	0	0	0	4.5	4.5	6.5	6.5	6.5	6.5	6.5	7
7.....	8	0	0	0	4.5	4.5	6.5	6.5	6.5	6.5	6.5	7
8.....	8	0	0	0	4.5	4.5	6.5	6.5	6.5	6.5	6.5	7
9.....	8	0	0	0	4.5	4.5	6.5	6.5	6.5	6.5	6.5	7
10.....	8	0	0	0	4.5	4.5	6.5	6.5	6.5	6.5	6.5	7
11.....	8	0	0	0	4.5	4.5	6.5	6.5	6.5	6.5	6.5	7
12.....	8	0	0	0	4.5	4.5	6.5	6.5	6.5	6.5	6.5	7
13.....	8	0	0	0	4.5	4.5	6.5	6.5	6.5	6.5	6.5	7
14.....	8	0	0	0	4.5	4.5	6.5	6.5	6.5	6.5	6.5	7
15.....	8	0	0	0	4.5	4.5	6.5	6.5	6.5	6.5	6.5	7
16.....	8	0	0	0	4.5	4.5	6.5	6.5	6.5	6.5	6.5	7
17.....	8	0	0	0	4.5	4.5	6.5	6.5	6.5	6.5	6.5	7
18.....	8	0	0	0	4.5	4.5	6.5	6.5	6.5	6.5	6.5	7
Average.....	4.7	4.5	4.2	3.6	4.6	5.6	6.3	7.7	10.1	11.8	14.1	15.6
Percentage of maximum.....	4.7	4.5	4.2	3.6	4.6	5.6	6.3	7.7	10.1	11.8	14.1	15.6
Range, in degrees.....	8	7	4	0	7	15	20	30	48	61	78	89
Sum, in degrees.....	0.140	0.125	0.119	0.095	0.311	0.441	0.489	0.720	1.000	1.280	1.560	1.840
Percentage of maximum.....	23	21	20	16	22	23	24	27	31	37	45	51

TABLE IX.—Wind velocity (in miles per hour) during oats transpiration period at Akron, Colo., from August 4 to 18, 1912

Date.	Hour ending—											
	A. M.						P. M.					
	1	2	3	4	5	6	7	8	9	10	11	12
Aug. 4.....	10.5	10.2	11.1	7.6	8.3	5.0	7.5	8.0	7.0	7.2	8.5	15.4
5.....	13.5	10.0	4.4	5.0	4.4	5.0	6.0	5.0	5.0	5.0	5.0	3.1
6.....	13.5	10.0	4.4	5.0	4.4	5.0	6.0	5.0	5.0	5.0	5.0	3.1
7.....	13.5	10.0	4.4	5.0	4.4	5.0	6.0	5.0	5.0	5.0	5.0	3.1
8.....	13.5	10.0	4.4	5.0	4.4	5.0	6.0	5.0	5.0	5.0	5.0	3.1
9.....	13.5	10.0	4.4	5.0	4.4	5.0	6.0	5.0	5.0	5.0	5.0	3.1
10.....	13.5	10.0	4.4	5.0	4.4	5.0	6.0	5.0	5.0	5.0	5.0	3.1
11.....	13.5	10.0	4.4	5.0	4.4	5.0	6.0	5.0	5.0	5.0	5.0	3.1
12.....	13.5	10.0	4.4	5.0	4.4	5.0	6.0	5.0	5.0	5.0	5.0	3.1
13.....	13.5	10.0	4.4	5.0	4.4	5.0	6.0	5.0	5.0	5.0	5.0	3.1
14.....	13.5	10.0	4.4	5.0	4.4	5.0	6.0	5.0	5.0	5.0	5.0	3.1
15.....	13.5	10.0	4.4	5.0	4.4	5.0	6.0	5.0	5.0	5.0	5.0	3.1
16.....	13.5	10.0	4.4	5.0	4.4	5.0	6.0	5.0	5.0	5.0	5.0	3.1
17.....	13.5	10.0	4.4	5.0	4.4	5.0	6.0	5.0	5.0	5.0	5.0	3.1
18.....	13.5	10.0	4.4	5.0	4.4	5.0	6.0	5.0	5.0	5.0	5.0	3.1
Average.....	13.5	10.0	4.4	5.0	4.4	5.0	6.0	5.0	5.0	5.0	5.0	3.1

The smoothness of the graphs obtained by this method of composites is in evidence in figure 4. The radiation curve is again seen to be symmetrical with reference to the noon hour and to decrease in either direction, at first slowly and then rapidly, to zero, a type of curve characteristic of clear days. The air temperature, wet-bulb depression, and transpiration all reach their maximum about two hours later. The transpiration graph for oats, like that for wheat, gives evidence of a slight depression or undue flattening after 9 a. m. In other words, one would expect from the corresponding slopes of the radiation and temperature curves that the transpiration graph would be more convex through the period from 9 a. m. to 2 p. m., provided the oat plant responds as a free physical system. It will be noted that the transpiration rate also falls off more rapidly in the afternoon than does the air temperature or the wet-bulb depression. In this respect the transpiration graph corresponds rather strikingly with the solar-radiation and wind-velocity graphs. The increase in wind velocity during the night does not, however, produce a corresponding increase in transpiration. This point will be referred to again. Finally, it is of interest to note that the transpiration loss of oats under Akron conditions during the night hours is extremely small, compared with the loss during the day.

SORGHUM

The sorghum transpiration measurements, like those made with wheat and oats, were conducted inside the screened inclosure and include three varieties of *Andropogon sorghum*—namely, Minnesota Amber, milo, and Dwarf milo¹ (Table X).

The environmental measurements for the corresponding period are given in Tables XI to XIV, inclusive.

¹ Minnesota Amber, A. D. L. 342-15; milo, S. P. I. No. 2496c; Dwarf milo, S. P. I. No. 2497c.

TABLE X.—Transpiration rate (in grams per hour) of sorghum, at Akron, Colo., from August 23 to 29, 1912

Variety.	Balance No.	Date.	Hour ending—												P. M.													
			A. M.						Noon.						P. M.													
			1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12		
Minnesota Amber.			B	Aug. 23	10	10	10	10	10	10	72	170	220	340	400	460	460	400	340	340	380	130	54	34	20	20	20	14
Do.	B	24	10	10	10	10	10	10	156	350	350	350	430	500	500	480	400	340	340	380	130	54	34	20	20	20	14	
Do.	B	25	10	10	10	10	10	10	156	350	350	350	430	500	500	480	400	340	340	380	130	54	34	20	20	20	14	
Do.	B	26	10	10	10	10	10	10	156	350	350	350	430	500	500	480	400	340	340	380	130	54	34	20	20	20	14	
Do.	B	27	4	4	4	4	4	4	13	30	100	180	210	450	500	520	530	470	370	244	136	46	28	24	16	80		
Do.	B	28	10	10	10	10	10	10	156	350	350	350	430	500	500	480	400	340	340	380	130	54	34	20	20	20	14	
Do.	B	29	10	10	10	10	10	10	156	350	350	350	430	500	500	480	400	340	340	380	130	54	34	20	20	20	14	
Milo.			C	Aug. 23	10	10	10	10	10	10	56	108	212	266	310	360	384	396	386	349	226	140	46	23	23	12	12	12
Do.	C	24	10	10	10	10	10	10	56	108	212	266	310	360	384	396	386	349	226	140	46	23	23	12	12	12	12	
Do.	C	25	10	10	10	10	10	10	56	108	212	266	310	360	384	396	386	349	226	140	46	23	23	12	12	12	12	
Do.	C	26	10	10	10	10	10	10	56	108	212	266	310	360	384	396	386	349	226	140	46	23	23	12	12	12	12	
Do.	C	27	2	2	2	2	2	2	36	100	180	240	300	380	440	410	360	280	190	130	50	30	20	18	16	10		
Do.	C	28	12	10	10	10	10	10	70	170	190	230	274	324	380	364	334	294	216	120	26	20	14	8	10	10		
Do.	C	29	10	10	10	10	10	10	70	170	190	230	274	324	380	364	334	294	216	120	26	20	14	8	10	10		
Dwarf milo.			D	Aug. 23	10	10	10	10	10	32	100	110	120	130	140	150	160	170	180	190	200	210	220	230	240	250	260	270
Do.	D	24	10	10	10	10	10	10	32	100	110	120	130	140	150	160	170	180	190	200	210	220	230	240	250	260	270	
Do.	D	25	10	10	10	10	10	10	32	100	110	120	130	140	150	160	170	180	190	200	210	220	230	240	250	260	270	
Do.	D	26	10	10	10	10	10	10	32	100	110	120	130	140	150	160	170	180	190	200	210	220	230	240	250	260	270	
Do.	D	27	2	2	2	2	2	2	8	50	130	190	260	320	340	380	400	334	264	186	70	44	30	24	20	14		
Do.	D	28	10	10	10	10	10	10	20	80	130	200	300	320	330	340	370	300	220	150	40	24	23	23	23	23		
Average.			12	11	11	10	10	20	72	150	206	282	336	384	405	402	368	307	212	144	35	26	20	17	13	12		
Percentage of maximum.			3	3	3	2	2	5	18	37	51	69	83	94	100	99	91	70	55	23	9	6	5	4	4	3		

TABLE XI.—Hourly solar radiation intensity (differential temperatures) during sorghum transpiration period, at Akron, Colo., from August 23 to 29, 1912

Date.	Weight.	Hour ending—												P. M.												
		A. M.						Noon.						P. M.												
		6	7	8	9	10	11	12	1	2	3	4	5	6												
Aug. 23	1	6	19	25	26	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
24	2	5	14	24	26	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
25	3	6	17	23	25	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47
26	4	7	18	24	26	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
27	5	8	19	25	27	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49
28	6	9	20	26	28	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
29	7	10	21	27	29	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51
Average.		6.5	16.8	22.7	26.3	29	30.4	31.4	32.4	33.4	34.4	35.4	36.4	37.4	38.4	39.4	40.4	41.4	42.4	43.4	44.4	45.4	46.4	47.4	48.4	49.5
Calories per sq. cm. per minute.		21	54	56	72	79	82	84	86	88	89	90	91	92	93	94	95	96	97	98	99	100	100	100	100	100
Percentage of maximum.																										

TABLE XII.—Hourly temperatures (in degrees Fahrenheit) during sorghum transpiration period, at Akron, Colo., from August 23 to 26, 1912¹

Date.	Weight.	Hour ending—																							
		A. M.												P. M.											
		1	2	3	4	5	6	7	8	9	10	11	Noon.	1	2	3	4	5	6	7	8	9	10	11	12
Aug. 23.....	1	57	56	55	57	55	60	68	73	78	82	88	89	90	90	91	90	86	80	74	70	64	61	58	65
24.....	2	63	60	59	57	56	63	68	72	76	81	85	87	88	89	87	87	84	76	68	66	65	60	53	66
25.....	3	63	62	61	60	58	62	67	71	75	80	87	91	94	94	93	94	89	80	74	73	75	71	67	66
26.....	2	60	65	63	61	60	67	69																	
Average.....	64	61.9	59.1	59.1	58.4	64	70.1	73.7	78.3	84.1	88.1	88.1	90.3	91.3	91.7	91.7	90	86.8	78.7	73	70.2	69.8	65.7	65.7	65.8
Average in degrees centigrade.....	17.8	16.6	15.1	15.1	14.7	17.8	21.2	23.2	25.7	28.9	31.2	32.4	32.9	33.2	33.2	33.2	32.2	30.4	25.9	21.2	21	18.7	18.7	18.8	
Percentage of maximum range.....	17	11	2	2	0	27	35	46	60	77	89	96	99	100	100	98	85	61	41	35	34	23	22	22	

¹ The thermograph record for this period is incomplete, but the days for which no record is given were similar in character to those recorded, as shown by the following maximum and minimum temperatures:

	Maximum.		Minimum.		
	°F.		°F.		
Aug. 23.....	93	56	Aug. 27.....	96	57
24.....	90	57	28.....	89	58
25.....	91	60	29.....	96	55
26.....	90	53			

TABLE XIII.—Hourly wet-bulb depression (in degrees Fahrenheit) during sorghum transpiration period, at Akron, Colo., from August 23 to 29, 1912

Date.	Hour ending—											
	A. M.						P. M.					
	1	2	3	4	5	6	7	8	9	10	11	12
Aug. 23.....	1 5.5	5 11.5	5 12	4.5 10.5	4 8.5	4.5 10	4.5 10.5	4 8.5	4.5 10	4.5 10.5	4 8.5	4.5 10
24.....	3 11	11.5 12	11 10.5	10.5 9	8.5 7.5	8.5 7.5	8.5 7.5	8.5 7.5	8.5 7.5	8.5 7.5	8.5 7.5	8.5 7.5
25.....	3 11	11.5 12	11 10.5	10.5 9	8.5 7.5	8.5 7.5	8.5 7.5	8.5 7.5	8.5 7.5	8.5 7.5	8.5 7.5	8.5 7.5
26.....	3 11	11.5 12	11 10.5	10.5 9	8.5 7.5	8.5 7.5	8.5 7.5	8.5 7.5	8.5 7.5	8.5 7.5	8.5 7.5	8.5 7.5
27.....	3 11	11.5 12	11 10.5	10.5 9	8.5 7.5	8.5 7.5	8.5 7.5	8.5 7.5	8.5 7.5	8.5 7.5	8.5 7.5	8.5 7.5
28.....	3 11	11.5 12	11 10.5	10.5 9	8.5 7.5	8.5 7.5	8.5 7.5	8.5 7.5	8.5 7.5	8.5 7.5	8.5 7.5	8.5 7.5
29.....	3 11	11.5 12	11 10.5	10.5 9	8.5 7.5	8.5 7.5	8.5 7.5	8.5 7.5	8.5 7.5	8.5 7.5	8.5 7.5	8.5 7.5
Average.....	7.8	7.5	7.2	6.7	6.3	5.8	5.6	5.6	5.5	5.4	5.3	5.2
Percentage of maximum range.....	10	8	7	4	2	0	4	13	46	64	77	89
Saturation deficit.....	0.222	0.166	0.179	0.167	0.179	0.178	0.178	0.178	0.178	0.178	0.178	0.178
Percentage of maximum.....	19	18	16	15	16	19	19	16	16	16	16	16

TABLE XIV.—Wind velocity (in miles per hour) during sorghum transpiration period, at Akron, Colo., from August 23 to 29, 1912

Date.	Hour ending—											
	A. M.						P. M.					
	1	2	3	4	5	6	7	8	9	10	11	12
Aug. 23.....	1 5.5	5 11.5	5 12	4.5 10.5	4 8.5	4.5 10	4.5 10.5	4 8.5	4.5 10	4.5 10.5	4 8.5	4.5 10
24.....	3 11	11.5 12	11 10.5	10.5 9	8.5 7.5	8.5 7.5	8.5 7.5	8.5 7.5	8.5 7.5	8.5 7.5	8.5 7.5	8.5 7.5
25.....	3 11	11.5 12	11 10.5	10.5 9	8.5 7.5	8.5 7.5	8.5 7.5	8.5 7.5	8.5 7.5	8.5 7.5	8.5 7.5	8.5 7.5
26.....	3 11	11.5 12	11 10.5	10.5 9	8.5 7.5	8.5 7.5	8.5 7.5	8.5 7.5	8.5 7.5	8.5 7.5	8.5 7.5	8.5 7.5
27.....	3 11	11.5 12	11 10.5	10.5 9	8.5 7.5	8.5 7.5	8.5 7.5	8.5 7.5	8.5 7.5	8.5 7.5	8.5 7.5	8.5 7.5
28.....	3 11	11.5 12	11 10.5	10.5 9	8.5 7.5	8.5 7.5	8.5 7.5	8.5 7.5	8.5 7.5	8.5 7.5	8.5 7.5	8.5 7.5
29.....	3 11	11.5 12	11 10.5	10.5 9	8.5 7.5	8.5 7.5	8.5 7.5	8.5 7.5	8.5 7.5	8.5 7.5	8.5 7.5	8.5 7.5
Average.....	7.8	7.5	7.2	6.7	6.3	5.8	5.6	5.6	5.5	5.4	5.3	5.2

The sorghum measurements were made during the latter part and the oat measurements during the first part of August. The amplitude and spread of the radiation curves for the two periods are essentially the same (see figs. 4 and 5). The air temperature during the sorghum period was, however, much higher, the average daily maximum being over 91°F. ,

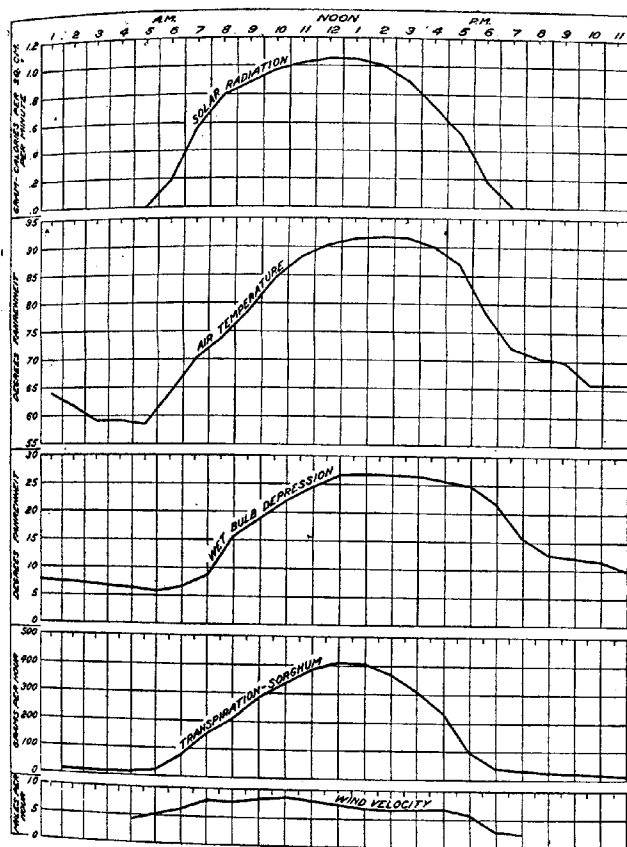


FIG. 5.—Composite transpiration graph of sorghum, with environmental graphs for corresponding period.

compared with a maximum of 79° during the oat period. There is also a corresponding difference in the wet-bulb depression, the mean maximum depression during the sorghum period being over 26° , compared with 17° during the oat period. The conditions were consequently more severe during the sorghum period—i. e., such as to induce a higher transpiration rate. Yet it will be seen, on reference to the transpiration graph

in figure 5, that sorghum, even under the more severe conditions imposed, gave no indication of a flattening of the peak of the transpiration curve. Furthermore, the maximum of the sorghum transpiration curve occurs at approximately noon, and the curve is nearly symmetrical. In brief, the transpiration graph of sorghum appears to follow more nearly the radiation curve than either wheat or oats. It is of interest in this connection to note that sorghum is one of the most efficient of the crop plants in the use of water, the sorghum varieties used in these experiments having a water requirement amounting to only 64 per cent of that of the oat plants.¹

RYE

The transpiration data for rye (*Secale cereale*)² on clear days are given in Table XV. These observations were made outside the inclosure, under freely exposed conditions, from June 22 to July 3, 1914. The environmental measurements for this period are given in Tables XVI to XX, inclusive. Hourly evaporation measurements from a free-water surface were also made in 1914, with the aid of an automatic balance. The hourly means for the environmental factors are plotted in figure 6, together with the hourly evaporation and the hourly transpiration of rye, the latter being represented by the mean of 12 automatic records taken on six different days.

¹ Based upon water-requirement measurements of the same plants. (Briggs and Shantz, 1914.)

² Spring rye, C. I. No. 73.

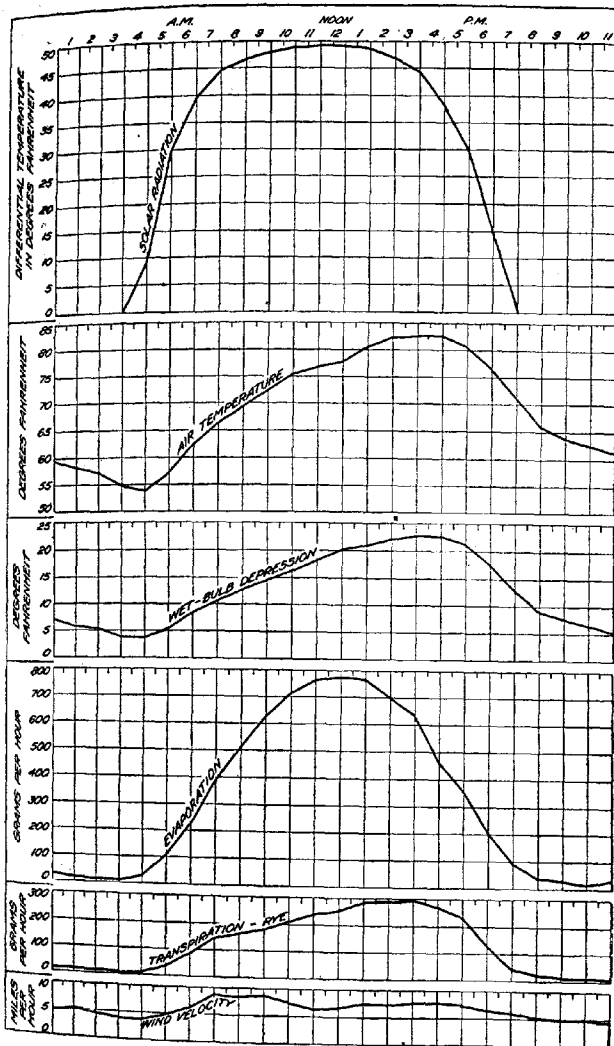


FIG. 6.—Composite transpiration graph of rye, with environmental graphs and evaporation graph for corresponding period.

TABLE XV.—Transpiration rate (in grams per hour) of rye, at Akron, Colo., during June and July, 1914

Date.	Ball sauce No.	Hour ending—															
		A. M.								P. M.							
		1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4
June 22	A					20	50	140	190	220	220	220	260	260	280	310	300
23	C					0	100	130	200	210	200	210	230	240	300	300	300
24	C	30	40	60	0	0	16	66	190	190	180	200	260	320	360	400	420
25	C	0	0	0	0	0	0	0	160	160	160	180	200	210	230	240	260
26	C	0	0	0	0	0	0	0	160	160	180	210	200	210	230	240	260
27	C	16	6	0	0	0	6	56	100	128	156	184	210	200	220	240	260
28	C	0	0	0	0	0	0	0	100	120	140	160	180	200	220	240	260
29	A	20	0	0	0	0	0	0	100	120	140	160	180	200	220	240	260
30	A	20	0	0	0	0	0	0	100	120	140	160	180	200	220	240	260
July 1	C	20	0	0	0	0	0	0	100	120	140	160	180	200	220	240	260
2	C	16	20	10	10	0	0	0	100	150	190	210	240	240	280	300	300
3	C					6	36	66	100	130	170	200	260	280	300	300	300
Average		16	14	14	8	10	38	84	144	166	187	214	240	254	286	290	294
Percentage of maximum		5	5	5	3	3	13	29	49	56	64	73	82	86	97	99	100

TABLE XVI.—Hourly solar radiation intensity (differential temperatures in degrees Fahrenheit) during rye transpiration period at Akron, Colo., in June and July, 1914

Date.	Hour ending—															
	A. M.								P. M.							
	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	
June 22	7	18	39	44	48	40-5	50	50	50	49	47	45	43	37	23	
23	7	13	30	46	48	50-5	58	50	48-5	48	46	44	40	34	20	
24	9	33	50	50	46	47	48	48-5	48-5	48-5	48-5	47	44	38	25	
July 1	7	45	38	43	46	47	48	48-5	48-5	48-5	48-5	47	44	38	25	
2	10	38	47	48	47	47	48	48-5	48-5	48-5	48-5	47	44	38	25	
3	10	38	47	48	47	47	48	48-5	48-5	48-5	48-5	47	44	38	25	
Average	10-3	37-5	39-2	44-3	46-7	48-0	48-6	49-1	49-0	48-4	46-7	44-2	41-0	36-3	24-7	
Calories per sq. cm. per minute	10-46	38	40	44	46	48	48	49	48	47	46	44	41	36	25	
Percentage of maximum	10	38	40	44	46	48	48	49	48	47	46	44	41	36	25	

TABLE XVII.—Hourly temperatures (in degrees Fahrenheit) during rye transpiration period at Akron, Colo., during June and July, 1914

Date.	Hour ending—												P. M.											
	A. M.						Noon																	
June 22.....	64	60	57.5	56.5	58.5	61.0	65.0	68.0	69.5	71.0	73.0	74.5	76	78	78.5	78.5	78.5	75.5	71	66	63.0	61.5	61.0	63
24.....	61	61	59.0	57.5	58.5	61.5	67.5	72.0	74.5	75.5	78.5	81.5	84	86	86.5	86.5	86.5	84.0	78	73	66.0	67.5	64.5	63
26.....	58	55	54.0	53.0	53.0	56.0	62.0	66.5	70.5	72.0	73.0	75.0	78	81	81.5	81.5	81.5	80.5	77	68	62.5	59.5	58.5	56
29.....	57	56.5	56.5	56.5	58.5	63.0	67.5	71	73.5	75	76	78	81.5	81.5	82.5	82.5	82.5	81.5	79	74	65	68	66.5	66.5
July 2.....	60	61	58	56	57	62.5	67	70	73	75	78.5	82.5	83	84	84.0	83.5	81.5	77.5	74	69	66	64	61.0	61.0
3.....	59.3	58.1	57.2	54.8	53.9	57.2	62.5	66.2	69.3	72.3	75.3	76.8	79.8	81.2	81.2	81.2	80.7	76.4	71.0	65.9	63.8	62.6	61.2	61.2
Average.....	15.2	14.5	14.0	12.7	12.2	14.0	16.9	19.0	20.7	22.4	24.1	24.9	26.6	27.3	27.9	28.0	28.1	27.1	24.7	21.7	18.8	17.7	17.0	16.2
Average in de- gree-centigrade range.....	29	15	12	3	0	12	39	43	54	64	75	80	90	95	99	100	93	78	60	42	35	30	25	25

TABLE XVIII.—Hourly wet-bulb depression (in degrees Fahrenheit) during rye transpiration period at Akron, Colo., in June and July, 1914

Date.	Hour ending—												P. M.											
	A. M.						Noon																	
June 22.....	7.0	5.7	5.4	3.9	3.8	5.4	8.4	10.6	12.8	14.5	16.1	16.2	20.1	20.8	22.0	22.8	22.7	31.2	17.5	12.8	9.0	7.6	6.4	4.7
24.....	7	4	5	3	1	3.5	9	11	12	12.5	14	15	16.5	18	18.5	19.5	19.5	19	16	11	7	5	5.5	5.5
26.....	7	4	5	3	1	3.5	9	11	12	12.5	14	15	16.5	18	18.5	19.5	19.5	19	16	11	7	5	5.5	5.5
29.....	7	4	5	3	1	3.5	9	11	12	12.5	14	15	16.5	18	18.5	19.5	19.5	19	16	11	7	5	5.5	5.5
July 2.....	7	4	5	3	1	3.5	9	11	12	12.5	14	15	16.5	18	18.5	19.5	19.5	19	16	11	7	5	5.5	5.5
3.....	4	4.5	4	3	1	3	7	10	12	15	17	18	21	23	24	24	24	23	20	16	12	11	8	7
Average.....	7.0	5.7	5.4	3.9	3.8	5.4	8.4	10.6	12.8	14.5	16.1	16.2	20.1	20.8	22.0	22.8	22.7	31.2	17.5	12.8	9.0	7.6	6.4	4.7
Percentage of maximum.....	17	10	8	1	0	8	24	36	47	56	65	76	86	90	96	100	100	92	73	47	27	20	14	5
Saturation def- icit.....	0.180	0.131	0.125	0.095	0.093	0.134	0.205	0.288	0.367	0.443	0.516	0.586	0.683	0.713	0.788	0.840	0.846	0.714	0.686	0.397	0.249	0.204	0.194	0.123
Percentage of maximum.....	22	16	16	12	11	16	32	35	44	54	64	71	83	89	95	99	100	88	83	48	30	25	23	15

Hour ending—

Date.	A. M.												P. M.											
	I	2	3	4	5	6	7	8	9	10	11	12	I	2	3	4	5	6	7	8	9	10	11	12
June 22	20	25	30	20	30	312	368	420	460	510	600	720	700	680	610	510	360	120	10	26				
24	60	60	60	0	0	212	270	330	500	510	610	720	740	730	620	520	330	120	10	26	40	0	0	
27	0	0	0	0	0	46	100	160	390	500	510	610	660	650	560	460	360	120	10	26	40	0	0	
30	10	0	0	0	0	0	240	350	480	560	780	700	700	600	630	560	330	120	10	26	40	0	0	
July 3	0	0	0	0	0	0	380	480	560	780	700	700	600	630	560	330	120	10	26	40	0	0	0	
5	0	0	0	0	0	0	280	380	480	560	780	700	700	600	630	560	330	120	10	26	40	0	0	
7	0	0	0	0	0	0	120	240	320	420	520	620	680	720	600	500	320	120	10	26	40	0	0	
10	0	0	0	0	0	0	280	380	480	560	780	700	700	600	630	560	330	120	10	26	40	0	0	
13	0	0	0	0	0	0	320	420	520	620	720	840	860	720	600	500	320	120	10	26	40	0	0	
16	0	0	0	0	0	0	320	420	520	620	720	840	860	720	600	500	320	120	10	26	40	0	0	
19	0	0	0	0	0	0	320	420	520	620	720	840	860	720	600	500	320	120	10	26	40	0	0	
22	25	15	14	10	27	107	326	390	514	616	715	701	707	700	618	463	348	293	93	39	29	16	34	
Average of 24 hours	3	3	2	1	4	24	99	51	67	82	93	99	100	100	91	83	60	47	26	13	5	4	3	

A striking feature of the radiation curve is the rapid rise in radiation intensity during the early morning hours. Reference to the graphs will show that the radiation has attained approximately one-half its maximum value two hours after sunrise, and a corresponding decrease occurs in the late afternoon.

The mean air temperature during the rye transpiration period ranged from 54° F. at 4.30 a. m. to about 83° F. at 4.30 p. m. The maximum air temperature thus occurs four hours later than the solar-radiation maximum. The wet-bulb-depression graph is similar in form to the air-temperature curve, and its maximum occurs at approximately the same time. The maximum of the evaporation curve, on the other hand, corresponds with that of solar radiation, but the slope of the evaporation graph is more nearly uniform during the morning and afternoon than that of the radiation graph.

The transpiration graph of rye shows the same flattening during the middle part of the day that was observed with wheat and oats in 1912. With rye this flattening begins at 8.30 a. m., and continues until 1 p. m., the slope being nearly uniform during this period. During the late afternoon the transpiration falls rapidly and the night transpiration is seen to be very low.

The mean wind velocity in miles per hour is plotted at the bottom of figure 6. The maximum rate of about 9 miles per hour occurs from 8 to 10 o'clock in the morning. During the night the rate is less than 5 miles per hour. There is little indication from the graphs that differences in the velocity of the wind had much influence on either the transpiration or the evaporation rate.

ALFALFA

The transpiration measurements upon alfalfa (*Medicago sativa*)¹ are the most extensive of the series and include 52 day records taken during 26 days, embracing late-season as well as midsummer measurements. The transpiration data are given in detail in Table XXI and the physical measurements in Table XXII to XXVI, inclusive. The hourly means will be found plotted in figure 7. Since the period covered by the measurements is so extended, it has seemed advisable also to separate the measurements into shorter periods for comparison. Summaries covering a short transpiration period in June and another period in October are accordingly presented in Tables XXVII and XXVIII, and are plotted in figure 15, to which reference will be made later.

¹ Grimm alfalfa, A. D. I. (Alkali and Drought Resistant Plant Investigations) No. 23.

TABLE XXI.—Transpiration rate (in grams per hour) of alfalfa at Akron, Colo., for long periods, in 1913 and 1914

Date.	Rel- ance No.	Hour ending—												P. M.											
		A. M.						Noon.																	
		1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
1913.																									
July 11.	A	0	0	0	0	0	90	40	110	160	180	160	110	180	220	250	280	180	160	190	30	4	4	4	4
12.	A	30	30	0	0	0	90	70	300	210	210	210	210	210	210	210	210	210	210	210	50	10	10	10	0
13.	A	0	0	0	0	0	120	160	200	210	210	210	210	210	210	210	210	210	210	210	10	10	10	10	0
Aug. 10.	A	4	4	4	4	40	20	120	120	200	240	240	240	240	240	240	240	240	240	240	10	10	10	10	4
11.	A	4	4	4	4	4	20	120	120	240	240	240	240	240	240	240	240	240	240	240	10	10	10	10	4
14.	A	4	4	4	4	4	20	120	120	240	240	240	240	240	240	240	240	240	240	240	10	10	10	10	4
1914.																									
June 18.	A	8	20	20	20	30	70	200	240	300	280	280	280	280	380	320	340	360	340	320	6	6	6	6	10
19.	A	10	10	10	10	10	10	190	230	280	330	360	360	360	440	440	440	440	440	440	100	20	20	20	0
20.	A	10	10	10	10	10	10	190	230	280	330	360	360	360	440	440	440	440	440	440	100	20	20	20	0
21.	A	0	0	0	0	0	10	190	230	280	330	360	360	360	440	440	440	440	440	440	100	20	20	20	0
Aug. 11.	A	10	10	10	10	10	10	190	230	280	330	360	360	360	440	440	440	440	440	440	100	20	20	20	0
12.	A	20	20	20	20	20	30	160	130	300	360	360	360	440	440	440	440	440	440	440	100	20	20	20	0
13.	A	20	20	20	20	20	30	160	130	300	360	360	360	440	440	440	440	440	440	440	100	20	20	20	0
14.	A	20	20	20	20	20	30	160	130	300	360	360	360	440	440	440	440	440	440	440	100	20	20	20	0
15.	A	20	20	20	20	20	30	160	130	300	360	360	360	440	440	440	440	440	440	440	100	20	20	20	0
16.	A	20	20	20	20	20	30	160	130	300	360	360	360	440	440	440	440	440	440	440	100	20	20	20	0
17.	A	20	20	20	20	20	30	160	130	300	360	360	360	440	440	440	440	440	440	440	100	20	20	20	0
18.	A	20	20	20	20	20	30	160	130	300	360	360	360	440	440	440	440	440	440	440	100	20	20	20	0
19.	A	20	20	20	20	20	30	160	130	300	360	360	360	440	440	440	440	440	440	440	100	20	20	20	0
20.	A	20	20	20	20	20	30	160	130	300	360	360	360	440	440	440	440	440	440	440	100	20	20	20	0
21.	A	20	20	20	20	20	30	160	130	300	360	360	360	440	440	440	440	440	440	440	100	20	20	20	0
22.	A	20	20	20	20	20	30	160	130	300	360	360	360	440	440	440	440	440	440	440	100	20	20	20	0
23.	A	20	20	20	20	20	30	160	130	300	360	360	360	440	440	440	440	440	440	440	100	20	20	20	0
24.	A	20	20	20	20	20	30	160	130	300	360	360	360	440	440	440	440	440	440	440	100	20	20	20	0
25.	A	20	20	20	20	20	30	160	130	300	360	360	360	440	440	440	440	440	440	440	100	20	20	20	0
26.	A	20	20	20	20	20	30	160	130	300	360	360	360	440	440	440	440	440	440	440	100	20	20	20	0
27.	A	20	20	20	20	20	30	160	130	300	360	360	360	440	440	440	440	440	440	440	100	20	20	20	0
28.	A	20	20	20	20	20	30	160	130	300	360	360	360	440	440	440	440	440	440	440	100	20	20	20	0
29.	A	20	20	20	20	20	30	160	130	300	360	360	360	440	440	440	440	440	440	440	100	20	20	20	0
30.	A	20	20	20	20	20	30	160	130	300	360	360	360	440	440	440	440	440	440	440	100	20	20	20	0
Oct. 1.	A	20	20	20	20	20	30	160	130	300	360	360	360	440	440	440	440	440	440	440	100	20	20	20	0
2.	A	20	20	20	20	20	30	160	130	300	360	360	360	440	440	440	440	440	440	440	100	20	20	20	0
3.	A	20	20	20	20	20	30	160	130	300	360	360	360	440	440	440	440	440	440	440	100	20	20	20	0
4.	A	20	20	20	20	20	30	160	130	300	360	360	360	440	440	440	440	440	440	440	100	20	20	20	0
5.	A	20	20	20	20	20	30	160	130	300	360	360	360	440	440	440	440	440	440	440	100	20	20	20	0

6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.	17.	18.	19.	20.	21.	22.	23.	24.	25.	26.	27.	28.	29.	30.	31.	32.	33.	34.	35.	36.	37.	38.	39.	40.	41.	42.	43.	44.	45.	46.	47.	48.	49.	50.	51.	52.	53.	54.	55.	56.	57.	58.	59.	60.	61.	62.	63.	64.	65.	66.	67.	68.	69.	70.	71.	72.	73.	74.	75.	76.	77.	78.	79.	80.	81.	82.	83.	84.	85.	86.	87.	88.	89.	90.	91.	92.	93.	94.	95.	96.	97.	98.	99.	100.	101.	102.	103.	104.	105.	106.	107.	108.	109.	110.	111.	112.	113.	114.	115.	116.	117.	118.	119.	120.	121.	122.	123.	124.	125.	126.	127.	128.	129.	130.	131.	132.	133.	134.	135.	136.	137.	138.	139.	140.	141.	142.	143.	144.	145.	146.	147.	148.	149.	150.	151.	152.	153.	154.	155.	156.	157.	158.	159.	160.	161.	162.	163.	164.	165.	166.	167.	168.	169.	170.	171.	172.	173.	174.	175.	176.	177.	178.	179.	180.	181.	182.	183.	184.	185.	186.	187.	188.	189.	190.	191.	192.	193.	194.	195.	196.	197.	198.	199.	200.	201.	202.	203.	204.	205.	206.	207.	208.	209.	210.	211.	212.	213.	214.	215.	216.	217.	218.	219.	220.	221.	222.	223.	224.	225.	226.	227.	228.	229.	230.	231.	232.	233.	234.	235.	236.	237.	238.	239.	240.	241.	242.	243.	244.	245.	246.	247.	248.	249.	250.	251.	252.	253.	254.	255.	256.	257.	258.	259.	260.	261.	262.	263.	264.	265.	266.	267.	268.	269.	270.	271.	272.	273.	274.	275.	276.	277.	278.	279.	280.	281.	282.	283.	284.	285.	286.	287.	288.	289.	290.	291.	292.	293.	294.	295.	296.	297.	298.	299.	300.	301.	302.	303.	304.	305.	306.	307.	308.	309.	310.	311.	312.	313.	314.	315.	316.	317.	318.	319.	320.	321.	322.	323.	324.	325.	326.	327.	328.	329.	330.	331.	332.	333.	334.	335.	336.	337.	338.	339.	340.	341.	342.	343.	344.	345.	346.	347.	348.	349.	350.	351.	352.	353.	354.	355.	356.	357.	358.	359.	360.	361.	362.	363.	364.	365.	366.	367.	368.	369.	370.	371.	372.	373.	374.	375.	376.	377.	378.	379.	380.	381.	382.	383.	384.	385.	386.	387.	388.	389.	390.	391.	392.	393.	394.	395.	396.	397.	398.	399.	400.	401.	402.	403.	404.	405.	406.	407.	408.	409.	410.	411.	412.	413.	414.	415.	416.	417.	418.	419.	420.	421.	422.	423.	424.	425.	426.	427.	428.	429.	430.	431.	432.	433.	434.	435.	436.	437.	438.	439.	440.	441.	442.	443.	444.	445.	446.	447.	448.	449.	450.	451.	452.	453.	454.	455.	456.	457.	458.	459.	460.	461.	462.	463.	464.	465.	466.	467.	468.	469.	470.	471.	472.	473.	474.	475.	476.	477.	478.	479.	480.	481.	482.	483.	484.	485.	486.	487.	488.	489.	490.	491.	492.	493.	494.	495.	496.	497.	498.	499.	500.	501.	502.	503.	504.	505.	506.	507.	508.	509.	510.	511.	512.	513.	514.	515.	516.	517.	518.	519.	520.	521.	522.	523.	524.	525.	526.	527.	528.	529.	530.	531.	532.	533.	534.	535.	536.	537.	538.	539.	540.	541.	542.	543.	544.	545.	546.	547.	548.	549.	550.	551.	552.	553.	554.	555.	556.	557.	558.	559.	560.	561.	562.	563.	564.	565.	566.	567.	568.	569.	570.	571.	572.	573.	574.	575.	576.	577.	578.	579.	580.	581.	582.	583.	584.	585.	586.	587.	588.	589.	590.	591.	592.	593.	594.	595.	596.	597.	598.	599.	600.	601.	602.	603.	604.	605.	606.	607.	608.	609.	610.	611.	612.	613.	614.	615.	616.	617.	618.	619.	620.	621.	622.	623.	624.	625.	626.	627.	628.	629.	630.	631.	632.	633.	634.	635.	636.	637.	638.	639.	640.	641.	642.	643.	644.	645.	646.	647.	648.	649.	650.	651.	652.	653.	654.	655.	656.	657.	658.	659.	660.	661.	662.	663.	664.	665.	666.	667.	668.	669.	670.	671.	672.	673.	674.	675.	676.	677.	678.	679.	680.	681.	682.	683.	684.	685.	686.	687.	688.	689.	690.	691.	692.	693.	694.	695.	696.	697.	698.	699.	700.	701.	702.	703.	704.	705.	706.	707.	708.	709.	710.	711.	712.	713.	714.	715.	716.	717.	718.	719.	720.	721.	722.	723.	724.	725.	726.	727.	728.	729.	730.	731.	732.	733.	734.	735.	736.	737.	738.	739.	740.	741.	742.	743.	744.	745.	746.	747.	748.	749.	750.	751.	752.	753.	754.	755.	756.	757.	758.	759.	760.	761.	762.	763.	764.	765.	766.	767.	768.	769.	770.	771.	772.	773.	774.	775.	776.	777.	778.	779.	780.	781.	782.	783.	784.	785.	786.	787.	788.	789.	790.	791.	792.	793.	794.	795.	796.	797.	798.	799.	800.	801.	802.	803.	804.	805.	806.	807.	808.	809.	810.	811.	812.	813.	814.	815.	816.	817.	818.	819.	820.	821.	822.	823.	824.	825.	826.	827.	828.	829.	830.	831.	832.	833.	834.	835.	836.	837.	838.	839.	840.	841.	842.	843.	844.	845.	846.	847.	848.	849.	850.	851.	852.	853.	854.	855.	856.	857.	858.	859.	860.	861.	862.	863.	864.	865.	866.	867.	868.	869.	870.	871.	872.	873.	874.	875.	876.	877.	878.	879.	880.	881.	882.	883.	884.	885.	886.	887.	888.	889.	890.	891.	892.	893.	894.	895.	896.	897.	898.	899.	900.	901.	902.	903.	904.	905.	906.	907.	908.	909.	910.	911.	912.	913.	914.	915.	916.	917.	918.	919.	920.	921.	922.	923.	924.	925.	926.	927.	928.	929.	930.	931.	932.	933.	934.	935.	936.	937.	938.	939.	940.	941.	942.	943.	944.	945.	946.	947.	948.	949.	950.	951.	952.	953.	954.	955.	956.	957.	958.	959.	960.	961.	962.	963.	964.	965.	966.	967.	968.	969.	970.	971.	972.	973.	974.	975.	976.	977.	978.	979.	980.	981.	982.	983.	984.	985.	986.	987.	988.	989.	990.	991.	992.	993.	994.	995.	996.	997.	998.	999.	1000.	1001.	1002.	1003.	1004.	1005.	1006.	1007.	1008.	1009.	1010.	1011.	1012.	1013.	1014.	1015.	1016.	1017.	1018.	1019.	1020.	1021.	1022.	1023.	1024.	1025.	1026.	1027.	1028.	1029.	1030.	1031.	1032.	1033.	1034.	1035.	1036.	1037.	1038.	1039.	1040.	1041.	1042.	1043.	1044.	1045.	1046.	1047.	1048.	1049.	1050.	1051.	1052.	1053.	1054.	1055.	1056.	1057.	1058.	1059.	1060.	1061.	1062.	1063.	1064.	1065.	1066.	1067.	1068.	1069.	1070.	1071.	1072.	1073.	1074.	1075.	1076.	1077.	1078.	1079.	1080.	1081.	1082.	1083.	1084.	1085.	1086.	1087.	1088.	1089.	1090.	1091.	1092.	1093.	1094.	1095.	1096.	1097.	1098.	1099.	1100.	1101.	1102.	1103.	1104.	1105.	1106.	1107.	1108.	1109.	1110.	1111.	1112.	1113.	1114.	1115.	1116.	1117.	1118.	1119.	1120.	1121.	1122.	1123.	1124.	1125.	1126.	1127.	1128.	1129.	1130.	1131.	1132.	1133.	1134.	1135.	1136.	1137.	1138.	1139.	1140.	1141.	1142.	1143.	1144.	1145.	1146.	1147.	1148.	1149.	1150.	1151.	1152.	1153.	1154.	1155.	1156.	1157.	1158.	1159.	1160.	1161.	1162.	1163.	1164.	1165.	1166.	1167.	1168.	1169.	1170.	1171.	1172.	1173.	1174.	1175.	1176.	1177.	1178.	1179.	1180.	1181.	1182.	1183.	1184.	1185.	1186.	1187.	1188.	1189.	1190.	1191.	1192.	1193.	1194.	1195.	1196.	1197.	1198.	1199.	1200.	1201.	1202.	1203.	1204.	1205.	1206.	1207.	1208.	1209.	1210.	1211.	1212.	1213.	1214.	1215.	1216.	1217.	1218.	1219.	1220.	1221.	1222.	1223.	1224.	1225.	1226.	1227.	1228.	1229.	1230.	1231.	1232.	1233.	1234.	1235.	1236.	1237.	1238.	1239.	1240.	1241.	1242.	1243.	1244.	1245.	1246.	1247.	1248.	1249.	1250.	1251.	1252.	1253.	1254.	1255.	1256.	1257.	1258.	1259.	1260.	1261.	1262.	1263.	1264.	1265.	1266.	1267.	1268.	1269.	1270.	1271.	1272.	1273.	1274.	1275.	1276.	1277.	1278.	1279.	1280.	1281.	1282.	1283.	1284.	1285.	1286.	1287.	1288.	1289.	1290.	1291.	1292.	1293.	1294.	1295.	1296.	1297.	1298.	1299.	1300.	1301.	1302.	1303.	1304.	1305.	1306.	1307.	1308.	1309.	1310.	1311.	1312.	1313.	1314.	1315.	1316.	1317.	1318.	1319.	1320.	1321.	1322.	1323.	1324.	1325.	1326.	1327.	1328.	1329.	1330.	1331.	1332.	1333.	1334.	1335.	1336.	1337.	1338.	1339.	1340.	1341.	1342.	1343.	1344.	1345.	1346.	1347.	1348.	1349.	1350.	1351.	1352.	1353.	1354.	1355.	1356.	1357.	1358.	1359.	1360.	1361.	1362.	1363.	1364.	1365.	1366.	1367.	1368.	1369.	1370.	1371.	1372.	1373.	1374.	1375.	1376.	1377.	1378.	1379.	1380.	1381.	1382.	1383.	1384.	1385.	1386.	1387.	1388.	1389.	1390.	1391.	1392.	1393.	1394.	1395.	1396.	1397.	1398.	1399.	1400.	1401.	1402.	1403.	1404.	1405.	1406.	1407.	1408.	1409.	1410.	1411.	1412.	1413.	1414.	1415.	1416.	1417.	1418.	1419.	1420.	1421.	1422.	1423.	1424.	1425.	1426.	1427.	1428.	1429.	1430.	1431.	1432.	1433.	1434.	1435.	1436.	1437.	1438.	1439.	1440.	1441.	1442.	1443.	1444.	1445.	1446.	1447.	1448.	1449.	1450.	1451.	1452.	1453.	1454.	1455.	1456.	1457.	1458.	1459.	1460.	1461.	1462.	1463.	1464.	1465.	1466.	1467.	1468.	1469.	1470.	1471.	1472.	1473.	1474.	1475.	1476.	1477.	1478.	1479.	1480.	1481.	1482.	1483.	1484.	1485.	1486.	1487.	1488.	1489.	1490.	1491.	1492.	1493.	1494.	1495.	1496.	1497.	1498.	1499.	1500.	1501.	1502.
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TABLE XXIII.—Hourly temperatures (in degrees Fahrenheit) during alfalfa transpiration period at Akron, Colo., for long periods, in 1913 and 1914

Date.	Hour ending—											
	A. M.						P. M.					
	1	2	3	4	5	6	7	8	9	10	11	12
1913.												
July 11.....	76	69	61.5	59.5	58	59.5	64	68	73.5	82	84	85
12.....	80	75	68.5	66.5	65	66.5	71	74	77	80	81	81.5
Aug. 10.....	81.5	78	74.5	72.5	70.5	71.5	73	76	78	80	81	81.5
Aug. 14.....	83	80	76.5	74.5	72.5	73.5	75	78	80	81	81	81.5
1914.												
June 18.....	59	58	58	59.5	60	64	68	73.5	79.5	82	84	86
19.....	65	61.5	61.5	61	59	58.5	64	73.5	79.5	82	84	86
20.....	65	60.5	60.5	60	58	57.5	62.5	67.5	73.5	79.5	82	84
Aug. 11.....	65	60.5	60.5	60	58	57.5	62.5	67.5	73.5	79.5	82	84
Sept. 1.....	55.5	55.5	55.5	55.5	55.5	55.5	55.5	55.5	55.5	55.5	55.5	55.5
18.....	61	63.5	62.5	59	58	60	71	80	84	86	87.5	88.5
19.....	62.5	61.5	61.5	60.5	59.5	60	65	72	78	80	81.5	82.5
20.....	62.5	61.5	61.5	60.5	59.5	60	65	72	78	80	81.5	82.5
21.....	62.5	61.5	61.5	60.5	59.5	60	65	72	78	80	81.5	82.5
22.....	62.5	61.5	61.5	60.5	59.5	60	65	72	78	80	81.5	82.5
23.....	62.5	61.5	61.5	60.5	59.5	60	65	72	78	80	81.5	82.5
24.....	62.5	61.5	61.5	60.5	59.5	60	65	72	78	80	81.5	82.5
25.....	62.5	61.5	61.5	60.5	59.5	60	65	72	78	80	81.5	82.5
26.....	62.5	61.5	61.5	60.5	59.5	60	65	72	78	80	81.5	82.5
27.....	62.5	61.5	61.5	60.5	59.5	60	65	72	78	80	81.5	82.5
28.....	62.5	61.5	61.5	60.5	59.5	60	65	72	78	80	81.5	82.5
29.....	62.5	61.5	61.5	60.5	59.5	60	65	72	78	80	81.5	82.5
30.....	62.5	61.5	61.5	60.5	59.5	60	65	72	78	80	81.5	82.5
Oct. 1.....	62.5	61.5	61.5	60.5	59.5	60	65	72	78	80	81.5	82.5
2.....	62.5	61.5	61.5	60.5	59.5	60	65	72	78	80	81.5	82.5
3.....	62.5	61.5	61.5	60.5	59.5	60	65	72	78	80	81.5	82.5
4.....	62.5	61.5	61.5	60.5	59.5	60	65	72	78	80	81.5	82.5
5.....	62.5	61.5	61.5	60.5	59.5	60	65	72	78	80	81.5	82.5
6.....	62.5	61.5	61.5	60.5	59.5	60	65	72	78	80	81.5	82.5
7.....	62.5	61.5	61.5	60.5	59.5	60	65	72	78	80	81.5	82.5
8.....	62.5	61.5	61.5	60.5	59.5	60	65	72	78	80	81.5	82.5
9.....	62.5	61.5	61.5	60.5	59.5	60	65	72	78	80	81.5	82.5
10.....	62.5	61.5	61.5	60.5	59.5	60	65	72	78	80	81.5	82.5
11.....	62.5	61.5	61.5	60.5	59.5	60	65	72	78	80	81.5	82.5
12.....	62.5	61.5	61.5	60.5	59.5	60	65	72	78	80	81.5	82.5
13.....	62.5	61.5	61.5	60.5	59.5	60	65	72	78	80	81.5	82.5
14.....	62.5	61.5	61.5	60.5	59.5	60	65	72	78	80	81.5	82.5
15.....	62.5	61.5	61.5	60.5	59.5	60	65	72	78	80	81.5	82.5
16.....	62.5	61.5	61.5	60.5	59.5	60	65	72	78	80	81.5	82.5
17.....	62.5	61.5	61.5	60.5	59.5	60	65	72	78	80	81.5	82.5
18.....	62.5	61.5	61.5	60.5	59.5	60	65	72	78	80	81.5	82.5
19.....	62.5	61.5	61.5	60.5	59.5	60	65	72	78	80	81.5	82.5
20.....	62.5	61.5	61.5	60.5	59.5	60	65	72	78	80	81.5	82.5
Average.....	51	49.8	49	48.3	47	47.2	50.7	58.2	65.7	69.7	73.8	76.1
Average in de- gree.....	10.6	9.9	9.4	9.1	8.3	8.4	10.4	18.7	20.9	23.2	24.5	25.5
Percentage of maximum range.....	12	9	6	4	0	1	11	34	69	82	89	95

TABLE XXIV.—Hourly wet-bulb depression (in degrees Fahrenheit) during alfalfa transpiration period at Akron, Colo., for long periods, in 1913 and 1914

Date.	Hour ending—												P. M.											
	A. M.												Noon.											
	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
1913.																								
July 11.....	10	6.5	3.5	6	7.5	5.2	8	12	14	16	19	20	21	21	21	20.5	20	19.5	17	14.5	12	10	9	7.5
Aug. 10.....	6.5	5.5	4	3	2.5	4	6	8.5	10.5	13	14.5	16.5	18	20	22	22	22.5	27	24	15	14	13	11	9
Aug. 14.....	5	4	3	2.5	3	5	9	12	16	17	19	20	21	21	24.5	25	26	24	18	15	13	11.5	10	9
June 18.....																								
June 19.....	6	4.5	4.5	4	4.5	5	8	10	14	16	20	21.5	24	26	27	25.5	24	20	15	7	5.5	6	8	9
Aug. 21.....	8	4.5	4.5	4.5	4.5	4.5	4.5	9	12	15	19	24	25	25	25	24	23	22	18	13	12	10	9	7
Sept. 10.....	3.5	3.5	3.5	3.5	3.5	3.5	3.5	5	8	10.5	13.5	16.5	18	21	23	24	24.5	24.5	19	14	13	10.5	8.5	7
Sept. 18.....	6	6	6	6	6	6	6	10	12	15	17.5	19.5	20	20	20	20.5	20.5	22.5	16	13	10.5	8.5	7.5	6.5
Oct. 1.....	4.5	4.5	4.5	4.5	4.5	4.5	4.5	7	10	12.5	15.5	17.5	18	18	18	18	18	18	15	13	10.5	8	6.5	5
Oct. 3.....	4.5	4.5	4.5	4.5	4.5	4.5	4.5	7	10	12.5	15.5	17.5	18	18	18	18	18	18	15	13	10.5	8	6.5	5
Oct. 5.....	4.5	4.5	4.5	4.5	4.5	4.5	4.5	7	10	12.5	15.5	17.5	18	18	18	18	18	18	15	13	10.5	8	6.5	5
Oct. 7.....	4.5	4.5	4.5	4.5	4.5	4.5	4.5	7	10	12.5	15.5	17.5	18	18	18	18	18	18	15	13	10.5	8	6.5	5
Oct. 9.....	4.5	4.5	4.5	4.5	4.5	4.5	4.5	7	10	12.5	15.5	17.5	18	18	18	18	18	18	15	13	10.5	8	6.5	5
Oct. 11.....	4.5	4.5	4.5	4.5	4.5	4.5	4.5	7	10	12.5	15.5	17.5	18	18	18	18	18	18	15	13	10.5	8	6.5	5
Oct. 13.....	4.5	4.5	4.5	4.5	4.5	4.5	4.5	7	10	12.5	15.5	17.5	18	18	18	18	18	18	15	13	10.5	8	6.5	5
Oct. 15.....	4.5	4.5	4.5	4.5	4.5	4.5	4.5	7	10	12.5	15.5	17.5	18	18	18	18	18	18	15	13	10.5	8	6.5	5
Oct. 17.....	4.5	4.5	4.5	4.5	4.5	4.5	4.5	7	10	12.5	15.5	17.5	18	18	18	18	18	18	15	13	10.5	8	6.5	5
Oct. 19.....	4.5	4.5	4.5	4.5	4.5	4.5	4.5	7	10	12.5	15.5	17.5	18	18	18	18	18	18	15	13	10.5	8	6.5	5
Oct. 21.....	4.5	4.5	4.5	4.5	4.5	4.5	4.5	7	10	12.5	15.5	17.5	18	18	18	18	18	18	15	13	10.5	8	6.5	5
Oct. 23.....	4.5	4.5	4.5	4.5	4.5	4.5	4.5	7	10	12.5	15.5	17.5	18	18	18	18	18	18	15	13	10.5	8	6.5	5
Oct. 25.....	4.5	4.5	4.5	4.5	4.5	4.5	4.5	7	10	12.5	15.5	17.5	18	18	18	18	18	18	15	13	10.5	8	6.5	5
Oct. 27.....	4.5	4.5	4.5	4.5	4.5	4.5	4.5	7	10	12.5	15.5	17.5	18	18	18	18	18	18	15	13	10.5	8	6.5	5
Oct. 29.....	4.5	4.5	4.5	4.5	4.5	4.5	4.5	7	10	12.5	15.5	17.5	18	18	18	18	18	18	15	13	10.5	8	6.5	5
Oct. 31.....	4.5	4.5	4.5	4.5	4.5	4.5	4.5	7	10	12.5	15.5	17.5	18	18	18	18	18	18	15	13	10.5	8	6.5	5
Average.....	5.8	4.6	4.2	3.8	3.2	3.6	5.3	9.6	13.5	17.3	20.3	22.1	23.6	24.5	25.0	26.3	27.7	19.3	12.0	10.5	9.0	7.9	6.9	6.9
Percentage of maximum.....	138	6	5	3	0	8	10	29	47	65	87	94	98	100	107	100	107	86	54	43	33	27	23	17
Saturation deficiency.....	0.126	0.092	0.091	0.087	0.082	0.087	0.107	0.246	0.377	0.490	0.602	0.682	0.726	0.756	0.786	0.796	0.776	0.616	0.386	0.316	0.246	0.216	0.186	0.156
Percentage of maximum.....	15	12	11	10	8	9	12	27	44	60	73	82	85	88	90	90	88	65	40	33	27	23	19	16

Hourly Transpiration Rate on Clear Days

TABLE XXV.—Wind velocity (in miles per hour) during alfalfa transpiration period at Akron, Colo., for long periods, in 1913 and 1914

Date.	Hour ending—											
	A. M.						P. M.					
	1	2	3	4	5	6	7	8	9	10	11	12
1913.												
July 11.....	10	10	7	7	9	13	12	11	10	9	8	8
12.....	5	5	5	5	5	5	5	5	5	5	5	5
13.....	1	1	1	1	1	1	1	1	1	1	1	1
14.....	1	1	1	1	1	1	1	1	1	1	1	1
1914.												
June 18.....	2	2	3	3	4	3	8	10	10	8	7	7
19.....	1	1	1	1	1	1	1	1	1	1	1	1
20.....	1	1	1	1	1	1	1	1	1	1	1	1
21.....	1	1	1	1	1	1	1	1	1	1	1	1
22.....	1	1	1	1	1	1	1	1	1	1	1	1
23.....	1	1	1	1	1	1	1	1	1	1	1	1
24.....	1	1	1	1	1	1	1	1	1	1	1	1
25.....	1	1	1	1	1	1	1	1	1	1	1	1
26.....	1	1	1	1	1	1	1	1	1	1	1	1
27.....	1	1	1	1	1	1	1	1	1	1	1	1
28.....	1	1	1	1	1	1	1	1	1	1	1	1
29.....	1	1	1	1	1	1	1	1	1	1	1	1
30.....	1	1	1	1	1	1	1	1	1	1	1	1
Oct.												
1.....	1	1	1	1	1	1	1	1	1	1	1	1
2.....	1	1	1	1	1	1	1	1	1	1	1	1
3.....	1	1	1	1	1	1	1	1	1	1	1	1
4.....	1	1	1	1	1	1	1	1	1	1	1	1
5.....	1	1	1	1	1	1	1	1	1	1	1	1
6.....	1	1	1	1	1	1	1	1	1	1	1	1
7.....	1	1	1	1	1	1	1	1	1	1	1	1
8.....	1	1	1	1	1	1	1	1	1	1	1	1
9.....	1	1	1	1	1	1	1	1	1	1	1	1
10.....	1	1	1	1	1	1	1	1	1	1	1	1
11.....	1	1	1	1	1	1	1	1	1	1	1	1
12.....	1	1	1	1	1	1	1	1	1	1	1	1
13.....	1	1	1	1	1	1	1	1	1	1	1	1
14.....	1	1	1	1	1	1	1	1	1	1	1	1
15.....	1	1	1	1	1	1	1	1	1	1	1	1
16.....	1	1	1	1	1	1	1	1	1	1	1	1
17.....	1	1	1	1	1	1	1	1	1	1	1	1
18.....	1	1	1	1	1	1	1	1	1	1	1	1
19.....	1	1	1	1	1	1	1	1	1	1	1	1
20.....	1	1	1	1	1	1	1	1	1	1	1	1
Average.....	4.6	4.6	4.8	4.4	4.3	4.9	5.8	6.8	7.4	8.3	8.2	8.1

TABLE XXVI.—Evaporation rate (in grams per hour) during alfalfa transpiration period at Akron, Colo., for long periods, in 1913 and 1914

Date.	Hour ending—											
	A. M.						P. M.					
	1	2	3	4	5	6	7	8	9	10	11	12
	Neon											
	1	2	3	4	5	6	7	8	9	10	11	12
July 11, 1913.	0	0	0	0	0	0	0	0	0	0	0	0
12	20	20	20	20	20	20	20	20	20	20	20	20
Aug. 10.	10	10	10	10	10	10	10	10	10	10	10	10
14.	7	7	7	7	7	7	7	7	7	7	7	7
June 18, 1914.	0	0	0	0	0	0	0	0	0	0	0	0
19	20	20	20	20	20	20	20	20	20	20	20	20
Aug. 11.	94	88	112	20	12	210	384	340	300	433	750	660
Sept. 10.	0	0	0	0	0	0	0	0	0	0	0	0
18.	14	20	0	0	0	0	68	212	400	520	780	840
20.	10	10	36	16	14	0	70	210	420	590	760	830
23.	16	16	34	50	0	0	180	230	320	400	480	560
24.	34	0	0	0	0	0	180	230	320	400	480	560
34.	80	60	90	18	33	0	133	288	430	560	610	680
36.	146	140	154	106	40	0	100	140	420	440	390	340
Oct. 3.	39	28	32	20	20	0	34	93	184	190	190	190
6.	0	0	0	0	0	0	43	44	168	140	440	550
14.	0	0	0	0	0	0	80	118	234	380	590	640
16.	20	20	20	20	20	20	80	140	260	330	400	480
17.	30	14	50	90	16	0	140	180	200	240	400	600
19.	10	10	10	10	10	10	150	268	372	510	580	600
20.	28	20	00	20	20	20	180	300	420	500	700	740
Average of Periods.	26	24	28	19	24	37	118	232	362	534	658	766
Per centum.	4	3	4	3	3	5	17	33	51	74	93	99

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Hourly Transpiration Rate on Clear Days

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TABLE XXVII.—Summary of transpiration and environmental conditions during alfalfa transpiration period at Akron, Colo., from June 18 to 21, 1914

Physical condition.	Hour ending—													
	A. M.							P. M.						
	1	2	3	4	5	6	7	8	9	10	11	12	1	2
Transpiration:														
Per minute:														
Percentage of max.														
Evaporation:														
Average:														
Percentage of max.														
Radiation:														
Average:														
Percentage of max.														
Calories per sq. cm.														
Air temperature:														
Average:														
Percentage of max.														
Wet-bulb:														
Average:														
Percentage of max.														
Saturated deficit:														
Average:														
Percentage of max.														
Wind velocity:														

17208°-16°

TABLE XXVIII.—Summary of transpiration and environmental conditions during alfalfa transpiration period, at Akron, Colo., from October 16 to 20, 1914

[illegible]

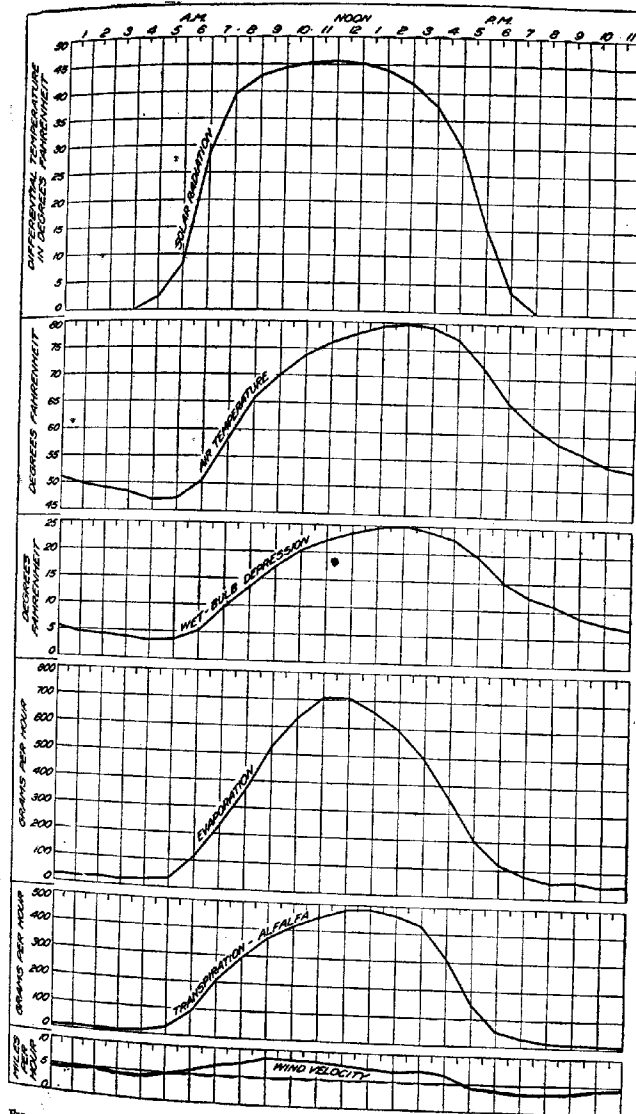


FIG. 7.—Composite transpiration graph of alfalfa, with environmental graphs and evaporation graph for corresponding period.

Considering now the composite graphs based upon the records obtained during 26 clear days, it will be seen that the radiation graph is similar in form to those already discussed, save that the radiation tends to change less rapidly during the early-morning and late-afternoon hours, owing to the fact that the length of the day was not uniform throughout this long period. The slight variation in radiation intensity during the midday hours and the marked changes between 5 and 7 a. m. and 4 and 6 p. m. are in conformity with what has already been noted of the other radiation curves.

The composite temperature graph shows a daily range of 33 degrees, the minimum (47° F.) occurring between 4 and 5 a. m., and the maximum (80° F.) between 2 and 3 p. m. The graph showing the wet-bulb depression is very similar in form to the air-temperature graph, and the maxima and minima correspond. This is to be expected, since with an unvarying amount of water vapor in the air, the wet-bulb depression would be determined by temperature fluctuations. Furthermore, since the observations are confined to clear days, sudden changes in absolute humidity are not encountered.

The evaporation graph representing the alfalfa period is nearly symmetrical with respect to noon, and the slope of the graph changes but slightly during either the morning or afternoon hours. The greater portion of the daily evaporation, however, takes place during the afternoon, owing probably to the higher temperature prevailing during this part of the day.

The transpiration graph shows a very low rate of transpiration during the night. The rate gradually increases from about one hour after sunrise to the maximum at 1.30 p. m. After 2.30 p. m. the curve falls rapidly until sundown and remains practically constant throughout the night. By far the greater part of the daily transpiration occurs during the afternoon. This asymmetry with respect to midday is much more apparent in the transpiration graph than in the evaporation graph.

At the bottom of figure 7 the mean velocity of the wind is shown for each hour in the day. During daylight hours the rate is approximately 7 miles per hour and during the night about 4 miles per hour. It is apparent from Table XXIV that the air is never still for an hour at a time.

AMARANTHUS

The transpiration data so far presented have been confined to crop plants. It is also desirable in this connection to study the transpiration of weeds or native plants which have shown themselves adapted to regions of limited rainfall. To this end, *Amaranthus retroflexus* was selected as a plant widely distributed throughout the cultivated areas of the United States. *Amaranthus* is also one of the most efficient plants known as regards the use of water, its water requirement at Akron being below 300, thus comparing favorably with the best of the prosoas, millets, and sorghums, the most efficient crop plants known.

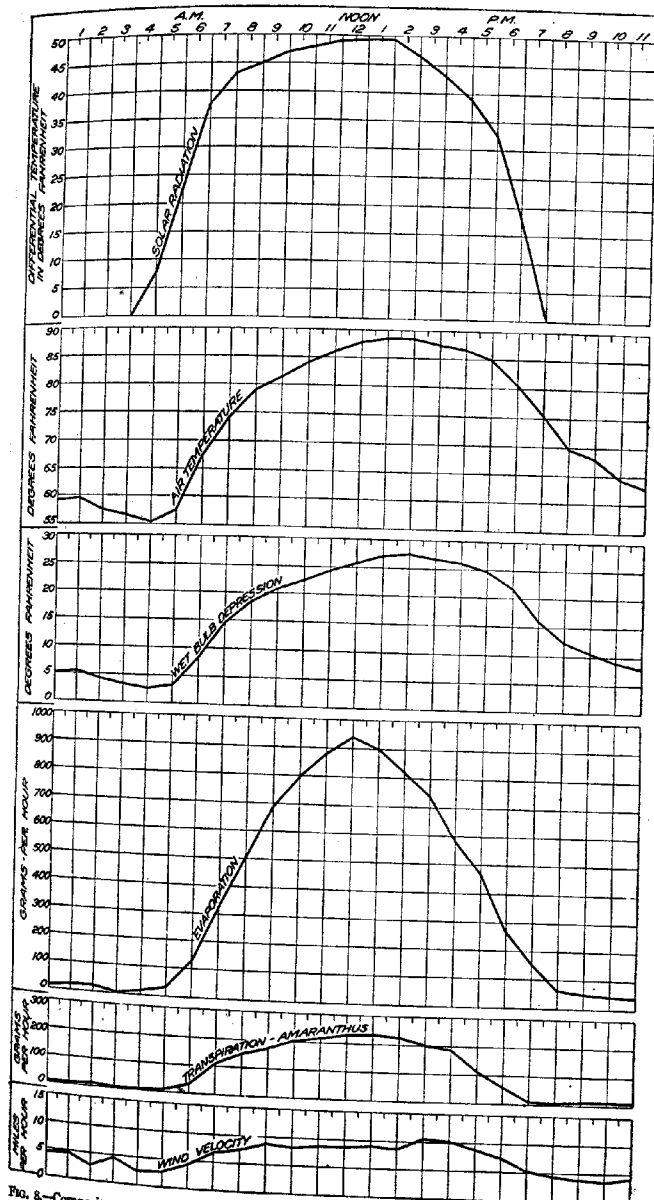


FIG. 8.—Composite transpiration...

TABLE XXIX.—Transpiration rate (in grams per hour) of *Amaranthus retroflexus* at Akron, Colo., from July 7 to 9, 1914

Date.	Balance No.	Hour ending—											
		A. M.						P. M.					
		1	2	3	4	5	6	7	8	9	10	11	12
July 7	A	0	0	0	20	0	15	65	80	90	160	168	180
8	C	0	0	0	0	0	8	16	74	90	100	180	180
9	A	10	10	20	0	0	10	40	140	180	210	230	230
Average	C	4	4	20	0	0	10	40	140	180	210	230	230
Percentage of maximum		2	6	10	3	2	6	32	112	152	173	202	215
		1	3	4	1	1	1	14	48	65	74	86	92

TABLE XXX.—Hourly solar radiation intensity (differential temperatures in degrees Fahrenheit) during *Amaranthus retroflexus* transpiration period at Akron, Colo., from July 7 to 9, 1914

Date.	Hour ending—											
	A. M.						P. M.					
	5	6	7	8	9	10	11	12	1	2	3	4
July 7	41.0	16	35	43	45	46	47.0	47	48	50	49	41
8	41.0	23	36	44	45	46	47.0	47	48	49	48	41
9	41.0	23	36	44	45	46	47.0	47	48	49	48	41
Average	41.0	23	36	44	45	46	47.0	47	48	49	48	41
Calories per sq. cm. per minute	7.7	92.7	37	43.3	44.7	46.7	48.3	49.0	49.3	49.3	49.0	48.3
Percentage of maximum	16	64	25	31	32	34	36	37	37	37	36	35

TABLE XXXI.—Hourly temperatures (in degrees Fahrenheit) during *Amaranthus* transpiration period at Akron, Colo., from July 7 to 9, 1914

Date.	Hour ending—													
	A. M.							P. M.						
	1	2	3	4	5	6	7	8	9	10	11	12	1	2
July 7.....	60	59	57.5	57.5	56	57	63	68	72	74	78	81	83	84
8.....	58	56	56	54	53	58	63	68	72	74	78	81	83	84
9.....	58	56	59	58	57	58	70	78	83	85	87	89	91	92
Average in de- grees centigrade	59.2	59.6	57.4	56.5	55.3	57.6	67.7	74.3	79.0	81.3	84.0	86.0	87.7	88.5
Percentage of maximum	15.1	15.3	14.1	13.6	12.9	14.2	19.8	23.5	26.1	27.4	28.9	30.0	30.9	31.4
Range.....	12	13	6	4	0	7	37	57	71	78	87	93	98	100

TABLE XXXII.—Hourly wet-bulb depression (in degrees Fahrenheit) during *Amaranthus retroflexus* transpiration period at Akron, Colo., from July 7 to 9, 1914

Date.	Hour ending—													
	A. M.							P. M.						
	1	2	3	4	5	6	7	8	9	10	11	12	1	2
July 7.....	4	4	2.5	3.0	1.0	0.5	4	8	10	11	14	17	21	22
8.....	4	4	4.0	2.0	2.0	3.0	8	17	21	25	26	27	28	29
9.....	5	5	5.0	5.0	5.0	6.0	13	19	24	26	27	29	30	31
Average.....	5.0	5.3	4.2	3.3	2.7	3.2	8.3	14.7	18.3	20.7	22.3	24.3	25.7	27.0
Percentage of maximum	11	6	3	0	2	23	49	63	73	80	88	94	99	100
Saturation defi- ciency.....	0.136	0.137	0.097	0.076	0.067	0.078	0.238	0.408	0.621	0.773	0.831	0.919	0.988	1.051
P. ct. inches.....	0.136	0.137	0.097	0.076	0.067	0.078	0.238	0.408	0.621	0.773	0.831	0.919	0.988	1.051
Range.....	13	9	7	6	7	23	47	59	68	78	78	94	100	100

The transpiration measurements (see Table XXIX) include six day records on three successive days in July. The corresponding physical measurements are given in Tables XXX to XXXIV, inclusive, and the hourly means are plotted in figure 8.

While these measurements were made during what we have termed "clear days," the sky was not wholly free from cumulus cloud during the period, and this is reflected in the radiation curve, which does not quite reach its normal value during the late morning hours.

Comparison with the conditions prevailing during the rye transpiration period, which extended over the two preceding weeks, will show that the evaporation was distinctly higher during the amaranthus period. The temperature during the latter period was slightly lower, but the saturation deficit was greater. Yet the transpiration graph of *Amaranthus retroflexus* gives no indication of the flattening which is so marked in the transpiration graph of rye. There appears then to be a marked difference in this respect in the response of the two plants to the march of radiation and other cyclic factors.

GENERAL DISCUSSION

It seems desirable at this point to summarize briefly the prevailing climatic conditions at Akron during the growth period of plants and more particularly during the transpiration periods included in the above determinations (Table XXXV). Akron is located in the rolling short-grass plains of northeastern Colorado. Absolutely clear days seldom occur, but often there are days with only a few light cumulus clouds in the sky, and during such days the plants are rarely shaded from the direct rays of the sun. Such brief interruptions in the direct radiation appear to have little influence on the hourly transpiration rate. On the other hand, there are many days during which cloudiness develops, especially in the afternoon, not infrequently accompanied by light rain and high wind. The number of days which may be classified as clear in the above-defined sense forms consequently a relatively small part of the growth period of the plants. The measurements presented in this paper have been made on practically cloudless days. The radiation intensity at midday on clear days in midsummer is normally about 1.4 calories per square centimeter per minute on a surface normal to the sun's rays. In the 1912 experiments the hazy condition of the atmosphere, together with the shading effect of the hail screen, combined to reduce the maximum radiation to 0.8 calorie during the wheat transpiration period, 1.02 calories during the oat transpiration period, and 1.05 calories during the sorghum measurements. The plants during the 1912 measurements were consequently obliged to dissipate only from 60 to 75 per cent as much solar energy as in the 1914 experiments.

TABLE XXXV.—Summary of plant and environmental data

CROP OF 1912					
	Wheat.				Mean for all varieties.
	Turkey.	Kharkov.	Kubanka.		
Transpiration period.....	June 25 to July 12	June 30 to July 5	June 25 to July 8	June 25 to July 12	
Date of cropping.....	Aug. 1	Aug. 1	Sept. 3		
Yield of dry matter..... gm.	344	366	220		
Mean maximum transpiration..... gm. per hour.	258	302	174		277
Maximum transpiration..... gm. per hour.	320	450	260		348
Mean maximum radiation, calories per sq. cm. per minute.....					
Mean maximum air temperature..... ° F.					8.8
Range in mean wind velocity.....					8.1
Mean maximum transpiration per gram of dry matter harvested.....	0.75	0.83	0.65		1.6 to 1.5
					0.77
CROP OF 1912					
	Oats.	Sorghum.			
	Swedish select.	Minnesota Amber.	Milo.	Dwarf Milo.	Mean for all varieties.
Transpiration period.....	Aug. 4 to 18	Aug. 23 to 29	Aug. 25 to 29	Aug. 24 to 29	Aug. 24 to 29
Date of cropping.....	Aug. 23	Sept. 26	Sept. 27	Sept. 27	
Yield of dry matter..... gm.	411	667	599	434	527
Mean maximum transpiration, gm. per hour.....	271	412	430	354	364
Maximum transpiration..... gm. per hour.	404				
Mean maximum radiation, calories per sq. cm. per minute.....	1.02				1.25
Mean maximum wet-bulb depression.....	17.1				26.3
Mean maximum saturation deficit, inches.....	0.602				1.18
Mean maximum air temperature..... ° F.	79.0				91.7
Range in mean wind velocity.....	2.5 to 6.7				2.4 to 6.7
Mean maximum transpiration per gram of dry matter harvested.....	0.66	0.62	0.84	0.82	0.7
CROP OF 1914					
	Rye.	Alfalfa.			Amaranthus.
		Early period.	Whole period.	Late period.	
Transpiration period.....	June 22 to July 3	June 18 to 21		Oct. 16 to 20	July 1 to 9
Date of cropping.....	July 23	July 11		Oct. 26	July 14
Yield of dry matter..... gm.	186	157		156	122
Mean maximum transpiration, gm. per hour.....	294	474	482	468	234
Mean maximum evaporation, gm. per hour.....	774	867	710	616	590
Mean maximum radiation, calories per sq. cm. per minute.....	1.38	1.34	1.28	1.21	1.38
Mean maximum wet-bulb depression.....	22.8	25.7	25.0	26	25.3
Mean maximum saturation deficit, inches.....	0.820	1.043	0.827	0.811	1.06
Mean maximum air temperature..... ° F.	82.6	89	79.7	77	88.3
Range in mean wind velocity.....	3.9 to 8.7	1.5 to 7	3.5 to 8.3	3.8 to 14.4	2.5 to 10.7
Mean maximum transpiration per gram of dry matter harvested.....	1.38	2.64		2.77	1.98

Since transpiration and evaporation are similarly affected by environmental factors, the loss of water from a free-water surface affords a good summation of the intensity of such factors. The total evaporation from a tank 8 feet in diameter with the water surface at ground level at Akron during the months from April to September, inclusive, is 44 inches, based on the records for seven seasons, compared with 33 inches at Dickinson in western North Dakota, 53 inches at Amarillo in the Panhandle of Texas, and 57 inches at Yuma, Ariz. In general, the evaporation increases as one proceeds from north to south through the Great Plains, and the same condition, though less marked, prevails from east to west. The transpiration conditions at Akron are probably as severe as may be found in cultivated areas east of the Rockies in this latitude (40° N.) or to the north of this parallel.

Hourly evaporation measurements with the shallow, blackened tank were not made in 1912. The evaporation rate in 1914 was highest during the amaranthus period, as would be expected from a consideration of the intensity of the environmental factors. The mean maximum evaporation rate for the different periods during the hours near midday ranged from 700 to 900 gm. per hour from a tank of 6,540 sq. cm. in area.¹

The highest temperatures and the greatest saturation deficits were encountered during the sorghum and amaranthus transpiration periods; yet these conditions produced no flattening of the peak of the transpiration curve of either plant, which is so marked in the case of wheat and rye. The lowest mean temperature and the smallest saturation deficit

¹ A loss of 1,000 gm. from the small tank corresponds to a loss of 0.0385 inch from the 8-foot tank referred to above, based on continuous records for the period, June 16 to September 19, 1914. The large tank loses more slowly during the forenoon, but more rapidly during the night. This is due to the heat capacity of the large tank. The records based on 24-hour periods show good agreement between the two tanks. To those who are more familiar with evaporation as measured by Livingston's atmometer, the following comparison with the shallow blackened evaporation tank used in our experiments will be of interest. The hourly evaporation graph of the porous-cup atmometers does not agree in form with the evaporation graph from the tank. The atmometers show a marked lag during the middle of the day as compared with the evaporation taking place from the tank. This might be anticipated, since the tank receives only the vertical component of the radiation, while the candle type of atmometer receives a smaller percentage of the total radiation at midday in midsummer than earlier or later in the day, due to the vertical walls. The difference is, however, very pronounced even with the new spherical form of porous cup. It is consequently impossible to establish a definite ratio between the evaporation from the Livingston atmometers and the shallow tank used in our experiments. The average ratio may, however, be given. From 6 a. m. to 6 p. m., on August 13 and 14, 1915, an evaporation of 1,000 c. c. from the tank corresponded to an evaporation of 6.5 c. c. from the white candle-type atmometers (1913); of 7.5 c. c. from the same type (1915); of 8.3 c. c. from the white, spherical type (1915); and of 10.9 c. c. from the black candle type (1915). The loss from the atmometers corresponding to 1,000 gm. loss from the shallow tank for different parts of the day is as follows:

* Type of atmometer.	6 to 10 a. m.	10 a. m. to 2 p. m.	2 to 6 p. m.
	a. m.	to 2 p. m.	p. m.
White candle type (1913).....	7.2	5.1	8.6
White candle type (1915).....	8.2	5.8	10.0
White spherical type (1915).....	9.1	6.7	10.3
Black candle type (1915).....	14.0	8.4	12.9

During the night the atmometers each lost about 3 gm. of water, while the tank showed a slight gain due to deposition of dew. None of these atmometers had ever been used in other measurements, and distilled water was used in all cases. The values given are based on the means of determinations with four atmometers of each type, after the observed evaporation from each atmometer had been multiplied by the standardization coefficient supplied with the apparatus.

occurred during the oat transpiration period. This may account for the fact that the flattening of the transpiration curve of oats is not so marked as in the case of the other cereals.

The wind velocity during these experiments, was higher during the daytime than during the night hours. There is a fairly well-defined maximum between 7 and 10 o'clock and another secondary maximum in the afternoon. Wind-still periods seldom occurred.

In Table XXXV are summarized the mean maximum values of the transpiration, evaporation, radiation, saturation deficit, and temperature for each period; and the yield, time of harvest, and the period during which transpiration measurements were made. The range in mean wind velocity and the mean maximum transpiration per gram of dry matter harvested have also been added to the table.

A comparison of the data for the three varieties of wheat shows a close agreement. Kharkov produced the highest yield and transpired at the highest rate. Kubanka produced the least dry matter and transpired at the lowest rate. On the basis of dry matter produced Kharkov transpired most rapidly and Kubanka least rapidly. From a consideration of unpublished data on the transpiration of cereals from seed time to harvest, these observations appear to have been taken during the period of maximum transpiration for the crops considered.

On the basis of transpiration throughout the total period of growth, the relative transpiration of Kharkov and Turkey wheat was the same—i. e., 365 ± 6 and 364 ± 6 gm. of water, respectively, for each gram of dry matter produced. Kubanka transpired relatively more—i. e., 394 ± 7 gm. of water for each gram of dry matter.

Oats transpired somewhat less rapidly than wheat in proportion to the amount of dry matter produced. A consideration of the temperature data shows the mean maximum temperature for the oat period to be about 7 degrees lower than for the wheat period. This difference in temperature and the resulting difference in humidity would be sufficient to account for the lower rate of transpiration of oats compared with wheat. On the basis of total transpiration, oats consumed 423 ± 5 gm. of water for each gram of dry matter produced, or 7 per cent more than Kubanka wheat.

Three different varieties of sorghum were used in the transpiration measurements—Minnesota Amber, milo, and Dwarf milo. The plants were apparently at the height of their transpiration during the measurements. The mean maximum transpiration rate of sorghum was higher in proportion to the dry matter harvested than for oats or wheat, but the physical conditions favored a more rapid transpiration during the sorghum period, as is shown by a comparison of the temperature, radiation, and saturation-deficit data. The slope of the sorghum transpiration curve near the peak is also much greater than for either wheat or oats.

The transpiration during the whole period of growth of sorghum, when based on dry matter produced, is practically the same for the three varieties here considered. Minnesota Amber transpired 239 ± 2 gm. of water for each gram of dry matter produced; Dwarf milo, 273 ± 4 gm.; and milo, 249 ± 3 grams.

The transpiration rate of rye, when based on the dry matter harvested, is much higher than for any other crop included in the 1912 water-requirement measurements. This is due in part to the more extreme atmospheric conditions prevailing during this period and in part to the higher water requirement of rye, which is 39 per cent higher than Kurbanka wheat and 15 per cent higher than Swedish Select oats.

The data presented during the long period for alfalfa were based on plants which yielded different amounts of dry matter. In order to make the comparison more exact, two short periods have been presented. The environmental conditions were somewhat more extreme during the early period, as is shown by a comparison of radiation, temperature, and saturation deficit. The evaporation rate was also higher. On the basis of dry matter harvested, the transpiration during the two periods was the same. It is necessary in this connection to consider the size of the plant at the actual time of the measurements. The late-period crop was harvested 6 days after the period when the transpiration measurements were made, while the early-period crop was harvested 20 days after the termination of the transpiration measurements. It is evident, therefore, that the ratio of transpiration rate to dry matter of the early-period crop would have been considerably higher had this crop been harvested soon after the transpiration measurements were completed.

The most severe environmental conditions in 1914 were encountered during the amaranthus period. Solar radiation was greater and saturation deficit, air temperature, and evaporation higher. On the basis of dry matter, amaranthus transpired less than alfalfa, but more than rye. On the basis of the whole period of growth, the water requirement of amaranthus was much less than rye, the higher rate of transpiration shown in the data here presented being due to the unusually severe conditions prevailing during this period.

While the writers are considering the data in this paper primarily from the standpoint of the relative transpiration rate of the different plants and are not particularly concerned with absolute values, it is interesting to find that the data here presented conform as nearly as can be expected to the relative transpiration rates of the different plants as determined from the water-requirement measurements.

COMPARISON OF THE FORM OF THE CURVES

In order that a more accurate comparison may be made between the form of the transpiration graph and that of the several environmental factors, the mean hourly values presented in the preceding tables have

also been expressed in terms of percentage of the maximum. In the case of temperature and wet-bulb depression, the calculation has been based on the maximum range—i. e., the mean minimum is taken as zero on the scale. The data for the various crops reduced to this uniform basis are presented in figures 9 to 15, inclusive, the axis of abscissas representing time and the axis of ordinates the percentage of the mean daily maximum (or mean daily range).

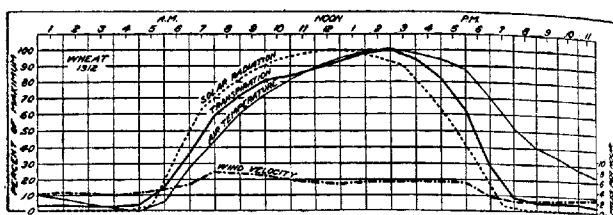


FIG. 9.—Graphs showing transpiration of wheat and the hourly values of cyclic environmental factors, all plotted in percentage of the maximum or maximum range.

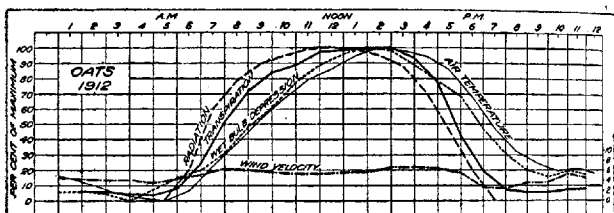


FIG. 10.—Graphs showing the hourly transpiration of oats and the hourly values of the cyclic environmental factors, all plotted in percentage of the maximum or maximum range.

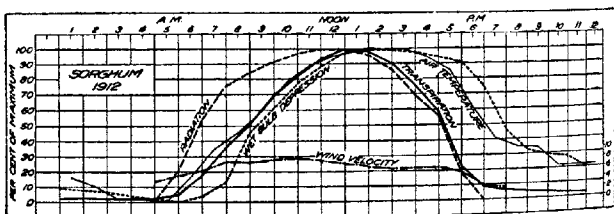


FIG. 11.—Graphs showing the hourly transpiration of sorghum and the hourly values of cyclic environmental factors, all plotted in percentage of the maximum or maximum range.

An inspection of the charts will show that the radiation graph rises in advance of the other cyclic environmental factors. This is to be expected, since the change in radiation is the primary cause of the cyclic change of the other components. For the same reason the radiation also rises in advance of the transpiration and falls either in advance of it, as in

the case of the three cereals wheat, oats, and rye, or approximately with the transpiration, as in the case of sorghum, alfalfa, and amaranthus.

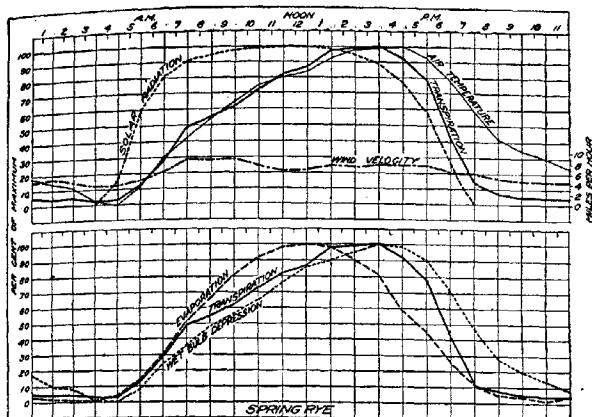


FIG. 12.—Graphs showing hourly transpiration of spring rye and the hourly values of the cyclic environmental factors, all plotted in percentage of the maximum or maximum range.

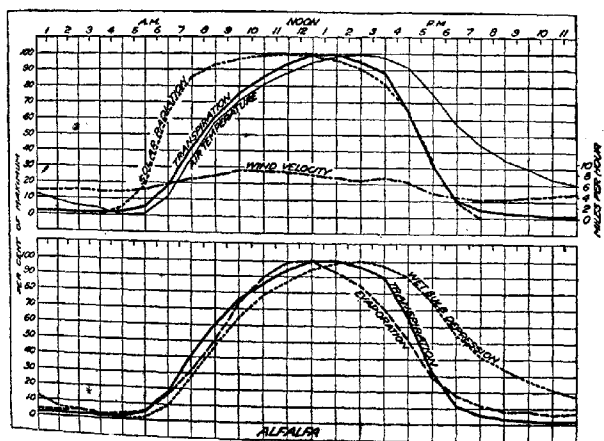


FIG. 13.—Graphs showing the hourly transpiration of alfalfa and the hourly values of cyclic environmental factors, all plotted in percentage of the maximum or maximum range.

This is clearly shown in figure 16, in which the two graphs are plotted for each plant.

The transpiration rises in advance of the temperature in the case of wheat, oats, and alfalfa; approximately with the temperature for rye

and sorghum; and later than the temperature for amaranthus. This is in evidence in figure 17, in which these two graphs alone are plotted for each plant measured. The transpiration in the afternoon always falls off far more rapidly than the temperature, and when the transpiration has reached the night level the temperature is still above the minimum by an amount corresponding roughly to one-third the daily range.

The wet-bulb depression and the air-temperature curves are very similar in form, owing to the fact that with a uniform absolute-moisture content of the air the former curve is determined strictly by the latter.

The transpiration rises in advance of the wet-bulb depression (fig. 18) in every instance except amaranthus, in which the graph starts later but crosses the wet-bulb depression curve about 9 a. m. The transpiration falls more rapidly than the wet-bulb depression in every instance.

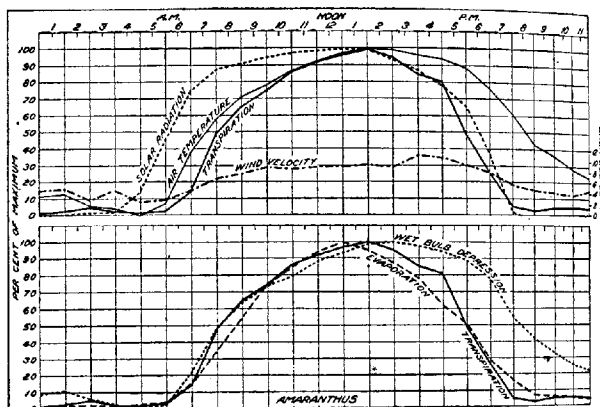


FIG. 14.—Graphs showing the hourly transpiration of *Amaranthus retroflexus* and the hourly values of the cyclic environmental factors, all plotted in percentage of the maximum or maximum range.

The evaporation rises later than the transpiration graph (fig. 19) in the case of alfalfa and amaranthus, owing to the fact that the tank evaporation is determined largely by the vertical component of the radiation, while isolated pots of plants probably receive radiation in excess of the vertical component. In the case of rye, the two graphs coincide during the early morning hours, but a marked depression of the transpiration curve from the evaporation graph occurs at 8 a. m., this difference persisting until after the evaporation graph has passed its maximum. The comparison of the two graphs brings out very strikingly the depression in the transpiration graph of rye during the morning hours, to which attention has already been called and which is a common feature of the cereals so far investigated.

The evaporation graph in the early afternoon falls in advance of the transpiration graphs, but owing to the greater slope of the transpiration

graphs in the late afternoon the two curves tend to reach the night level at about the same time.

DISTRIBUTION OF TRANSPIRATION IN RELATION TO SOLAR RADIATION

In Table XXXVI is given a summary of the data represented by the radiation and transpiration graphs shown in figure 16. The second column of this table shows the relative radiation received by the different

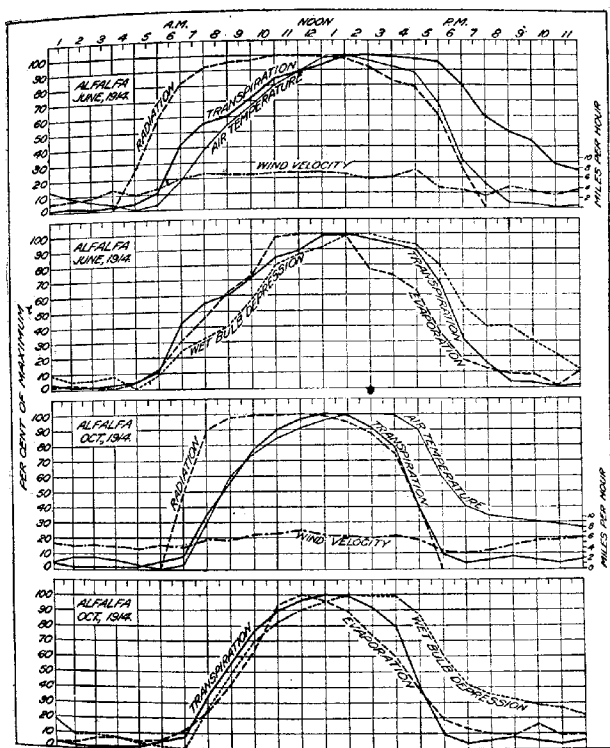


FIG. 15.—Graphs showing the hourly transpiration values of alfalfa for short periods in June and in October, with the hourly values of the cyclic environmental factors, all plotted in percentage of the maximum or maximum range.

crops, giving in arbitrary units the integrated area bounded by the radiation curve and the time axis. The integrated transpiration obtained in a similar manner is given in the third column. In the fourth column is given the ratio of the integrated transpiration to the integrated radiation for each particular crop.

It will be seen from these figures that the integrated transpiration for wheat and oats slightly exceeds the integrated radiation and that the reverse is true for rye, sorghum, amaranthus, and alfalfa. The transpiration curves for sorghum, amaranthus, and alfalfa lie almost wholly within the radiation curve. The ratio of the transpiration area to the radiation area is also low in the case of spring rye, owing to the comparatively low rate of transpiration during the morning hours.

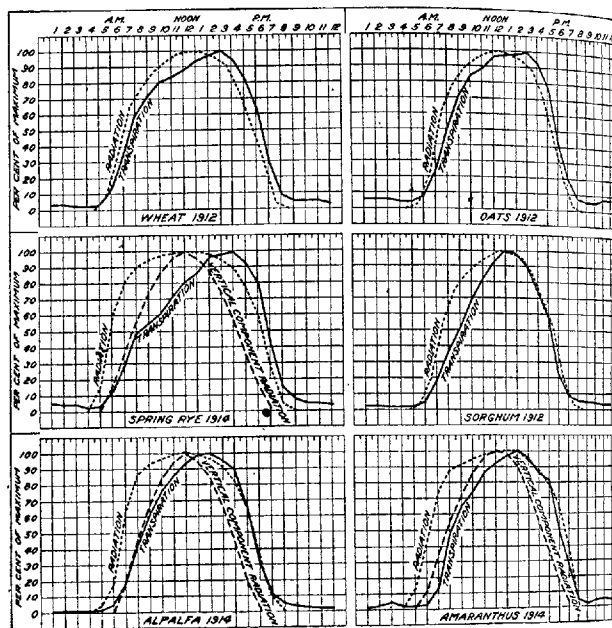


FIG. 16.—Comparison of the form of transpiration graphs with the graphs representing the total radiation and the vertical component of the radiation.

TABLE XXXVI.—A comparison of radiation and transpiration based on the area inclosed by the graphs in figure 17

Plant.	Area bounded by—		Ratio of transpiration to radiation area.	Transpiration.					
	Radiation graph.	Transpiration graph.		Area for day-light hours.	Day-light.	Night.	A. M.	P. M.	11 a. m. to 3 p. m.
Wheat	302	310	1.03	298	Per cent. 96	Per cent. 4	Per cent. 44	Per cent. 56	Per cent. 37
Oats	289	303	1.05	286	94	6	44	56	39
Rye	337	306	.86	290	95	5	38	62	36
Sorghum	283	253	.89	240	95	5	43	57	45
Amaranthus	346	284	.82	275	97	3	42	58	40
Alfalfa	315	271	.86	264	97	3	44	56	48

The last portion of Table XXXVI gives the relative transpiration for different parts of the day. The percentage of the transpiration taking place during daylight is very uniform, ranging from 94 per cent for oats to 97 per cent for amaranthus and alfalfa. The transpiration during the night is remarkably low, ranging from 3 per cent for amaranthus and alfalfa to 6 per cent for oats. The data as presented represent the integration of the transpiration and radiation for hourly intervals, so that the transpiration for the hour interval during which sunrise (or sunset) occurred has been included as daylight transpiration. The ratio can be more accurately determined from the automatic records, which show an

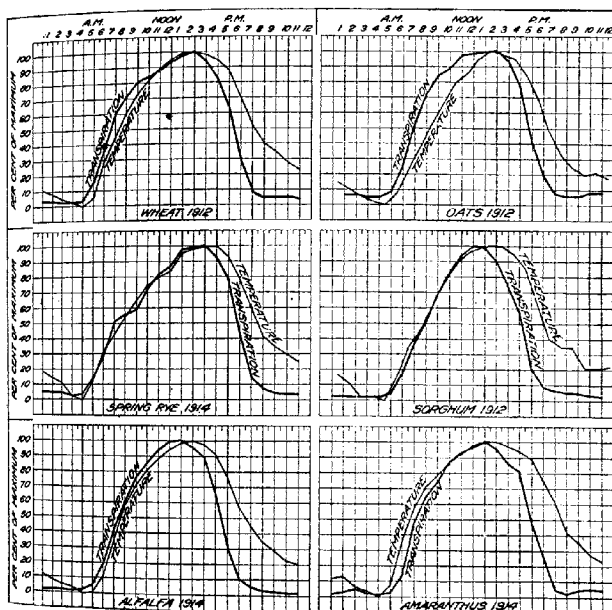


FIG. 17.—Comparison of the transpiration graphs plotted in percentage of the maximum with the temperature graphs plotted in percentage of the maximum range.

average night transpiration less than 5 per cent of that occurring during daylight. This low night transpiration is significant when we consider that the temperature and the saturation deficit are relatively high during the early hours of the night and that the dew point is seldom reached at Akron. The wind velocity at night is also at least one-half the average daylight velocity.

It will be seen from Table XXXVI that the transpiration in the forenoon is lower than in the afternoon, the difference being greatest in the case of rye and least in the case of wheat, oats, and alfalfa. For the

group of plants as a whole, 43 per cent of the transpiration took place before noon and 57 per cent in the afternoon, while the average radiation during the period was slightly greater in the forenoon.

In the last column of the table is given the percentage of transpiration taking place between 11 a. m. and 3 p. m. While these figures are not directly comparable, owing to the difference in the length of the day—i. e., in the number of daylight hours—it is clear that from one-third to

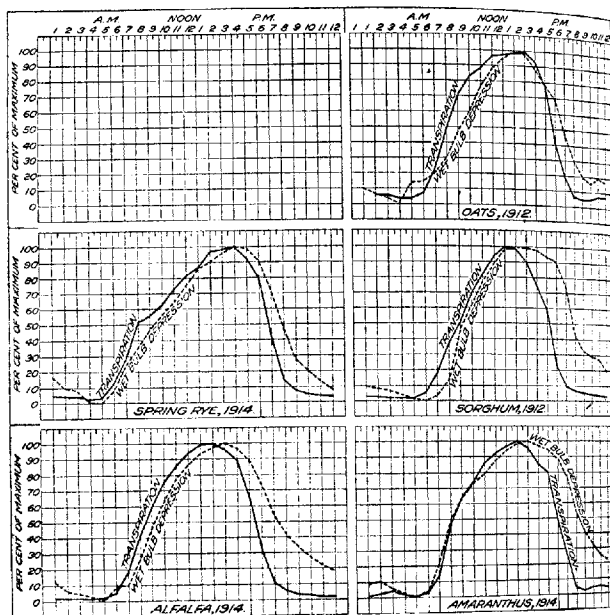


FIG. 18.—Comparison of transpiration with wet-bulb depression, both plotted in percentage of the maximum range.

one-half of the transpiration during the 24-hour period takes place from 11 a. m. to 3 p. m.

RATIO OF TRANSPIRATION TO EVAPORATION

Transpiration is often regarded as evaporation modified to some extent by plant structures and plant functions. Both are influenced by radiation, temperature, saturation deficit, and wind. Because of the similarity of the two processes, the evaporation rate has often been used as a standard to which the transpiration is referred.

Livingston (1906 and 1913) has given special attention to the relation of transpiration to evaporation, and has applied the terms "relative

transpiration," "transpiring power" (Livingston and Hawkins, 1915), to the ratio of the transpiration rate to the evaporation rate of his porous-cup atmometer. It has been shown¹ that the graphs representing transpiration and the evaporation from the porous-cup atmometer are similar in form, but that their maxima do not as a rule occur at the same time in plants exposed to extreme conditions. Furthermore, when the

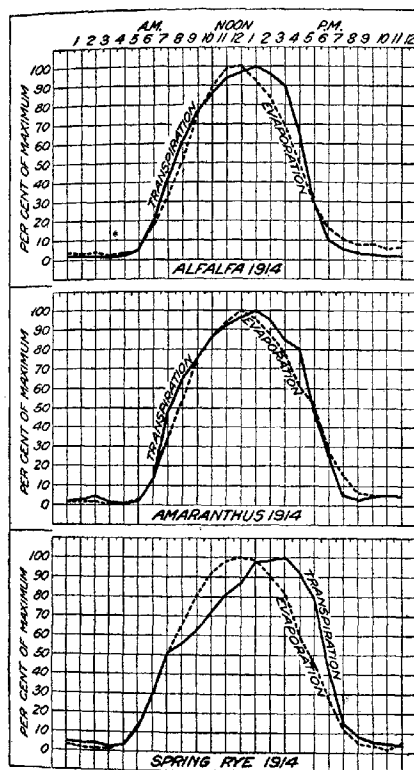


FIG. 19.—Comparison of the transpiration with the evaporation from a free-water surface in a shallow, blackened tank, both plotted in percentage of the maximum range.

ratio of the transpiration to evaporation (the relative transpiration) is plotted against time, the daily graph usually shows two maxima, one in the morning and a second in the afternoon.

Graphs representing the ratio of the transpiration rate of rye, alfalfa, and amaranthus to the evaporation rate are given in figure 20 and show

¹ See also Shreve, 1914; Bakke, 1914.

the maxima referred to in the investigations cited. One maximum occurs in the morning about 7 or 8 o'clock, and a second and greater maximum is found in the afternoon between 4 and 6 p. m.¹ In other words, the transpiration graph shows a tendency to rise earlier in the morning and fall later in the afternoon than the evaporation graph. This is evident in each of the three graphs presented in figure 20.

This result is capable of two quite dissimilar interpretations. If the assumption is made that evaporation constitutes a correct summation of the influence of environment on transpiration, it follows logically that the departure of the transpiration-evaporation ratio from a constant value is due to a decrease or increase in the transpiration coefficient. It must,

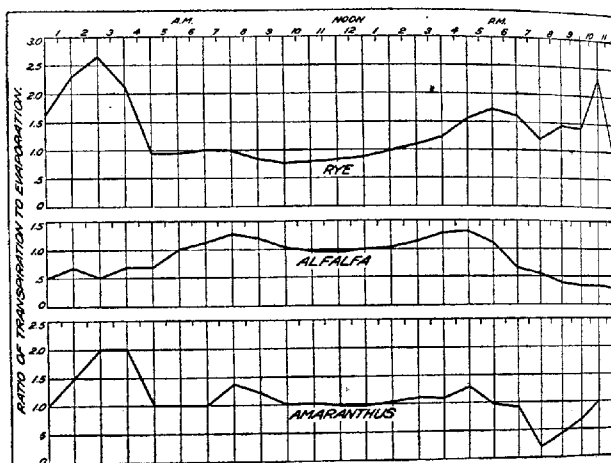


FIG. 20.—Graphs showing hourly ratio of transpiration to evaporation as plotted in figure 19.

however, be recognized that all evaporimeters do not respond to their environment in the same way. A large deep tank does not have the same daily graph as a shallow tank. A filter-paper evaporimeter does not follow the graph of the porous-cup atmometer. If none of these agree, can it be said without further proof that the evaporation rate of any one of them is proportional to the transpiration rate of a plant which responds freely to its environment? The fact that the transpiration graph is so uniformly asymmetrical with respect to noon in our determinations and that the evaporation graph is so uniformly symmetrical would indicate that the two processes were not controlled in the same way by the physical factors of the environment. The writers are inclined to the belief that

¹ The hourly values of transpiration and evaporation at night are so small that the observational errors make the ratio uncertain, and the night ratios will consequently not be considered at this time.

the departure of the transpiration from evaporation should not be taken as proof of a change in the transpiration coefficient of the plant and that it is safer for the present not to base conclusions on this assumption but instead to consider directly the factors which influence both transpiration and evaporation.

CORRELATION BETWEEN TRANSPIRATION AND ENVIRONMENTAL FACTORS

Two methods have been employed by the writers in making a quantitative investigation of the relationships existing between the transpiration of the plant and the intensity of its environment: (1) The coefficient of correlation between the transpiration and a given environmental factor has been computed as a basis for the determination of the relative influence of the various environmental factors and (2) the relationship between the mean hourly transpiration and the hourly values of the several environmental factors has been computed by the method of least squares, and the relative weights of the different environmental factors determined from the coefficients of the resulting equation. Such a reduction of the data appears highly desirable, for it affords a means of comparison independent of the personal element. The results of the correlation reductions will first be considered.

In computing the correlation coefficients,¹ the individual hourly observations as presented in Tables I to XXVI were used. The data in each instance embrace not less than three days' observations with the transpiration measurements in duplicate, so that the number of pairs of terms—i. e., the "population" considered—approximated 144 for the 3-day periods in the transpiration correlations and in other cases exceeded this number.

The correlation coefficients of the transpiration rate of alfalfa, amaranthus, and rye, with the intensity of the several environmental factors, are presented in Table XXXVII, together with the probable error of the correlation coefficient in each case.

¹ For a presentation of the theory and the method of computing correlation coefficients, see Yule (1912) and Lavenport (1907).

TABLE XXXVII.—Correlation between transpiration and environmental factors

Plant, period, and components.	Correlation coefficient.	Plant, period, and components.	Correlation coefficient.
Alfalfa (long period, Sept. 10 to Oct. 20, 1914):		Alfalfa (June 18, 19, 21, 1914)—Continued.	
Radiation and transpiration.....	0.840 ± 0.009	Wind velocity and transpiration.....	0.626 ± 0.036
Temperature and transpiration.....	.819 ± .011	Wind velocity and radiation.....	.641 ± .046
Wet-bulb and transpiration.....	.822 ± .011	Vertical radiation and transpiration..	.818 ± .013
Evaporation and transpiration.....	.838 ± .011	Amaranthus (July 7 to 9, 1914):	
Wind velocity and transpiration.....	.485 ± .026	Radiation and transpiration.....	.844 ± .016
Wind velocity and radiation.....	.302 ± .030	Temperature and transpiration.....	.849 ± .016
Alfalfa (Oct. 16 to 20, 1914):		Wet-bulb and transpiration.....	.842 ± .016
Radiation and transpiration.....	.886 ± .010	Evaporation and transpiration.....	.946 ± .006
Temperature and transpiration.....	.859 ± .012	Wind velocity and transpiration.....	.683 ± .031
Wet-bulb and transpiration.....	.843 ± .013	Wind velocity and radiation.....	.776 ± .032
Evaporation and transpiration.....	.929 ± .006	Vertical radiation and transpiration..	.863 ± .014
Wind velocity and transpiration.....	.353 ± .039	Rye (June 22 to July 3, 1914):	
Wind velocity and radiation.....	.275 ± .084	Radiation and transpiration.....	.820 ± .014
Vertical radiation and transpiration..	.862 ± .011	Temperature and transpiration.....	.854 ± .011
Alfalfa (June 18, 19, 21, 1914):		Wet-bulb and transpiration.....	.748 ± .018
Radiation and transpiration.....	.861 ± .015	Evaporation and transpiration.....	.894 ± .033
Temperature and transpiration.....	.788 ± .021	Wind velocity and transpiration.....	.376 ± .036
Wet-bulb and transpiration.....	.852 ± .008	Wind velocity and radiation.....	.353 ± .047
Evaporation and transpiration.....	.888 ± .012	Vertical radiation and transpiration..	.766 ± .017

An inspection of the correlation table will show that, excluding evaporation, the highest correlation is obtained between radiation and transpiration. The correlation coefficient for these components is remarkably uniform for the different crops and periods, ranging from 0.82 to 0.88, the lowest value occurring in the case of rye, as one might expect from the form of the transpiration graph.

The similarity in the form of the composite graphs for air temperature and wet-bulb depression would lead to the expectation that their correlation coefficients with transpiration would be similar and the coefficients are in fact nearly the same. The only exceptions are (1) alfalfa (June period), in which the wet-bulb depression shows the higher correlation with transpiration; and (2) rye, in which temperature is the more closely

correlated. Reference to figures 12 and 17 shows the unusually close agreement between the composite transpiration graph for rye and the temperature graph.

The correlation coefficient of temperature (or wet-bulb depression) and transpiration also agrees approximately with that of radiation and transpiration. In other words, it appears from a consideration of these coefficients that radiation, temperature, and wet-bulb depression show an equally close association with the daily transpiration cycle. The correlation of temperature and wet-bulb depression with transpiration may, however, be looked upon as being in part associative with radiation rather than causative, as will appear from the following considerations.

The degree of correlation¹ between radiation and transpiration (from 0.82 to 0.88) indicates that the radiation determines the transpiration to the extent of from 0.67 to 0.77, the square of the correlation coefficients, if radiation is regarded as the primary causative factor. The remainder (0.33 to 0.23) is to be ascribed to other factors. If temperature is taken as a causative factor of transpiration, the correlation coefficients show a dependence of transpiration upon temperature of from 0.62 to 0.74; but this is far in excess of the remainder (0.33 to 0.23) to be accounted for. In other words, the sum of the squares of the two correlation coefficients is in excess of unity. This means, then, that temperature and radiation are intercorrelated. A similar intercorrelation exists between radiation and wet-bulb depression, and an exact differentiation is impossible. However, since these factors are physically dependent upon radiation, we may assign to radiation the total effect indicated by the correlation coefficient, keeping always clearly in mind the assumption involved. On this basis the radiation intensity determines two-thirds to three-fourths of the transpiration at Akron on clear days; or all other factors combined have only from one-third to one-half the influence of radiation.

On the other hand, if it is preferred to look upon radiation, temperature, and wet-bulb depression as direct independent causative factors (which must also be recognized as involving a specific assumption to this effect), then it is evident from Table XXXVII that these factors play approximately an equal part in determining transpiration on clear days. Not only are the correlation coefficients very nearly the same for the different factors with a given crop, but they vary but slightly for the different plants investigated.

¹ While a correlation coefficient of unity denotes perfect correlation, a correlation coefficient of less than unity must not be interpreted as determining the relationship in proportion to the magnitude of the correlation coefficient, for even in the case of a primary causative factor the relationship can not be greater than the square of the correlation coefficient. For example, a correlation coefficient of 0.707 between a causative and a resultant term indicates a dependence of the latter upon the former of 0.5—i. e., the square of 0.707. This may be easily demonstrated by computing the correlation coefficient between either of two series of numbers, each having a normal frequency distribution, with the product of one series by the other. The correlation coefficient of the product series with either primary series will be found to be 0.707. In other words, each series determines the product series to the extent of 0.5, while the two series together determine the product series absolutely.

In order to decide between these two assumptions, other evidence is necessary; and this may be found in a consideration of the transpiration during the night—i. e., when the radiation received by the plants is nil.

In Table XXXVIII are summarized the transpiration and wet-bulb depression (in percentage of the maximum) and the air temperature (in percentage of the maximum range) for the hours 3 to 4 a. m. and 8 to 9 p. m. It is evident from the table that a simultaneous diminution in the wet-bulb depression of one-fourth of its maximum and in temperature of one-third of its maximum range results in a drop of only 3 per cent in the transpiration rate. This would seem to indicate that the high correlation obtained between transpiration and air temperature (or wet-bulb depression) is largely due to the direct correlation between radiation and temperature (or wet-bulb depression).¹

TABLE XXXVIII.—Comparison of transpiration, temperature, and wet-bulb depression at 3 to 4 a. m. and 8 to 9 p. m.

Crop or period.	Per cent of maximum transpiration.			Per cent of maximum temperature.			Per cent of maximum wet-bulb depression.		
	3 to 4 a. m.	8 to 9 p. m.	Difference in a. m. and p. m. reading.	3 to 4 a. m.	8 to 9 p. m.	Difference in a. m. and p. m. reading.	3 to 4 a. m.	8 to 9 p. m.	Difference in a. m. and p. m. reading.
Wheat.....	3	5	2	3	40	37	.....	.....	.....
Oats.....	4	6	2	2	24	22	21	37	16
Rye.....	3	7	4	3	42	39	17	39	22
Sorghum.....	2	5	3	2	34	32	25	48	23
Amaranthus.....	1	3	2	4	42	38	12	45	33
Alfalfa.....	2	3	1	4	35	31	15	42	27
June period.....	2	3	1	3	49	46	19	47	28
October period.....	1	7	6	5	32	27	2	38	36
Mean.....	.....	.....	3	.....	.....	34	.....	.....	26

If we ascribe to radiation a causative effect equal to that indicated by the correlation coefficient with transpiration, it becomes possible also to investigate the influence of wind velocity on transpiration by a process of elimination similar to that employed above.

Transpiration in still air is somewhat less than in moving air, since the latter tends to reduce the distance that the transpired moisture must move in order to find free-air conditions. In other words, the wind tends to increase the diffusion gradient, and so increases the transpiration (or evaporation) rate. But a slight movement appears to satisfy this condition, and the correlation coefficients between wind and transpiration (Table XXXVII) show that the variation in wind at Akron, where some wind nearly always occurs, has little influence on the trans-

¹ In opposition to this view it may be argued that the plants from 3 to 4 a. m. are more turgid than from 8 to 9 p. m. This is undoubtedly true, but it is also true that during the last named period the plants are more turgid than at 3 or 5 p. m., the period during which the maximum transpiration rate was observed.

piration rate. In arriving at this conclusion it is again necessary to consider the correlation not only between wind and transpiration, but also between wind and radiation. If the wind influences transpiration independently of its association with radiation, the wind velocity must show a higher correlation with transpiration than with radiation. This occurs only during the long alfalfa period, in which there appears to be a slight effect due to wind. In all other cases the wind correlation with transpiration differs from the wind correlation with radiation by an amount not greater than the probable error of the difference. Here, again, we are making the specific assumption that the radiation is the primary causative factor, so that if wind is associated with transpiration to an extent no greater than with radiation its effect on transpiration is slight. This assumption is here again supported by the fact that the transpiration is extremely low during the night hours, although the wind is blowing.

If transpiration and evaporation are largely determined by the same factors or, in other words, if transpiration is essentially a physical process, then a high correlation between transpiration and evaporation is to be expected. Reference to Table XXXVII will show that the correlation of evaporation with transpiration ranges from 0.84 to 0.95. The latter value is slightly higher than the maximum correlation (0.89) of radiation with transpiration and shows that 0.9 of the transpiration was in this instance determined by the same factors which determined the transpiration.

The relation of evaporation to transpiration is to be considered as associative rather than causative, both responding to the same environmental factors, but not necessarily in precisely the same way or to the same degree. The extent of this association furthermore depends upon the manner in which evaporation is measured. For example, the evaporation rate from a free-water surface in a very shallow tank conforms much more closely to the transpiration rate than when a deep tank is used, since the latter, on account of its large heat capacity, stores up a large amount of energy which is dissipated through evaporation during the night. It is evident that the evaporimeter must simulate the plant system as nearly as possible in absorption and heat capacity if a high degree of correlation between the two is to be attained.

LEAST-SQUARE RELATIONSHIPS BETWEEN TRANSPIRATION (OR EVAPORATION) AND ENVIRONMENTAL FACTORS

The method of least squares affords a means of determining the relative influence of the various environmental factors upon the transpiration. In these least-square reductions (Merriman, 1893, and Bartlett, 1915) the mean hourly values have been used, and it has been assumed that the relationship is linear in character—i. e., that the transpiration varies directly in proportion to the intensity of the environmental factors.

The results of the least-square reductions are presented graphically in figures 21 and 22. In all cases, the vertical component of the radiation has been employed rather than the radiation on a surface normal to the sun's rays. The reason for this will be apparent from an inspection of the radiation and transpiration charts, where it will be seen that during the early morning hours the slope of the radiation graph is much greater than that of the transpiration graph for rye, alfalfa, and amaranthus. In other words, the transpiration rate does not increase nearly as rapidly as the normal component of the radiation during the early daylight hours. In a field of grain or alfalfa, considered as a whole, it is evident that the vertical component of the radiation would alone be effective. In the case of an isolated pot of plants standing on the transpiration scale, the horizontal component would also be effective. The extent to which this enters can not be directly determined, however, and in the following discussion the vertical component has been used throughout.¹

TRANSPIRATION AS DETERMINED BY RADIATION AND TEMPERATURE

The observed and computed transpiration graphs, the latter based on the assumption that the vertical component of the radiation and the air temperature are the primary controlling factors in transpiration, are given in figure 21. The computed equations are as follows:

For rye..... $0.384 R_v + 0.642 \theta = T$;

For alfalfa..... $0.514 R_v + 0.539 \theta = T$;

For amaranthus..... $0.546 R_v + 0.443 \theta = T$;

in which

R_v is the vertical component of radiation,

θ is the temperature rise, and

T is the transpiration.

In the above equations and in those which follow the hourly values for each term are expressed as a percentage of the maximum. In other words, the general dimensionless equation is of the form:

$$a \frac{R'_v}{R'_{v_{max}}} + b \frac{\theta' - \theta'_0}{\theta'_{max} - \theta'_0} = \frac{T'}{T'_{max}}$$

in which the primed quantities represent observed values.

¹ *Calculation of the vertical component of radiation.*—If R represents the normal component of the radiation of the sun, R_v the vertical component, and h the altitude—i. e., the angular distance of the sun above the horizon—then: $R_v = R \sin h$.

Expressing the altitude in terms of declination and hour angle (Smithsonian Institution, 1894, p. lxviii), we have $\sin h = \sin \phi \sin \delta + \cos \phi \cos \delta \cos t$, in which

ϕ —the latitude of the place of observation;

δ —the declination of the sun—i. e., the angular distance above or below the Equator (from U. S. Navy Dept., 1912); and

t —the hour angle—i. e., the angle between the meridian plane through the place and the meridian plane through the sun.

Substituting, we have:

$R_v = R (\sin \phi \sin \delta + \cos \phi \cos \delta \cos t)$.

The daily observations are expressed on the basis of mean sun time, which introduces a slight error in the calculation of the vertical radiation component.

An inspection of the curves in figure 21 will show that the computed graph agrees with the observed transpiration graph much better in the morning than in the afternoon.¹ The computed graph always reaches its maximum in advance of the observed graph. The greater departures occur during the early afternoon and early evening. The agreement is by no means as good as is to be desired, and the graphs show clearly that transpiration can not be completely accounted for on the assumption

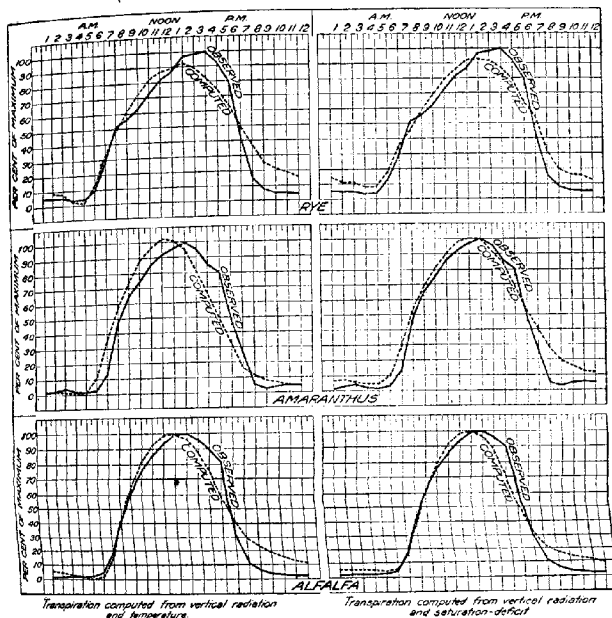


FIG. 21.—Graphs showing the observed transpiration with that computed from vertical radiation and temperature (on the left) and from vertical radiation and saturation deficit (on the right).

that the vertical component of radiation and the rise in temperature are the controlling factors.

The relative values of the computed coefficients are of interest. In the case of alfalfa, the radiation is weighted 0.97 relative to temperature; amaranthus, 1.23; and rye, 0.60. In this connection it should be recalled that rye shows a sudden change in the slope of the transpiration graph in the morning, differing markedly from alfalfa and amaranthus in this respect.

¹ Since preparing figures 21 and 22 a recalculation based on more exact determinations of the vertical component of radiation has given computed values of transpiration and evaporation which are in somewhat closer agreement with the observed values during the daylight hours than those indicated in the charts. The coefficients in the equations are based upon the revised calculation.

TRANSPIRATION AS DETERMINED BY RADIATION AND SATURATION DEFICIT

Corresponding graphs based upon vertical radiation and saturation deficit are also given in figure 21. The values for the latter term are computed from the mean hourly wet-bulb depression and the corresponding hourly air temperatures. The resulting equations follow:

For rye $0.455 R_v + 0.622 D = T$;

For alfalfa..... $0.538 R_v + 0.553 D = T$;

For amaranthus..... $0.538 R_v + 0.481 D = T$;

in which D represents the saturation deficit expressed as a percentage of

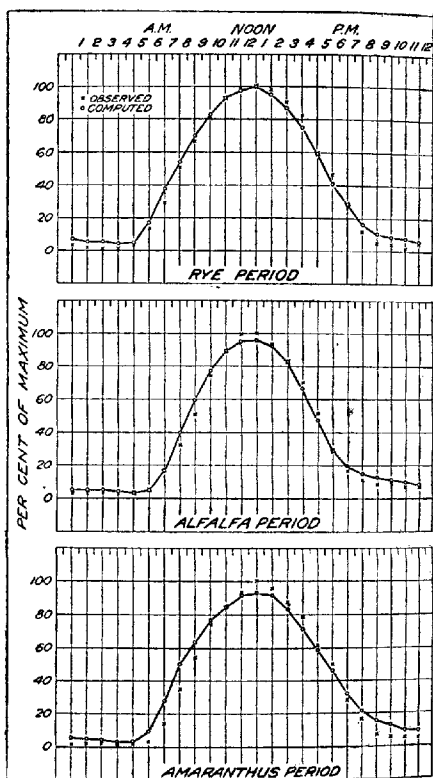


FIG. 22.—Graphs showing the observed evaporation with that computed by least-square methods from the vertical component of radiation and the saturation deficit.

the maximum, and the other symbols have the same meaning as before. An inspection of the graphs shows them to be similar in form to those computed from radiation and temperature. The coefficients are also

similar to those of the former series. The ratio of the radiation to the saturation-deficit coefficient for the different plants is as follows: Rye, 0.73; alfalfa, 0.97; amaranthus, 1.12. The equation for rye again shows the radiation to have the lesser influence of the two factors considered, while in the case of the other two plants, the radiation has an equal or greater influence. The equations for the latter plants are in fair agreement, but in all cases discrepancies occur between the observed and computed curves, particularly during the early afternoon and early evening hours.

EVAPORATION AS DETERMINED BY RADIATION AND SATURATION DEFICIT

The evaporation rate from the shallow, blackened tank for the three transpiration periods just considered has also been computed, assuming the vertical radiation and the saturation deficit to be the controlling environmental factors. The observed and computed evaporation graphs are given in figure 22. The agreement during the rye and alfalfa periods is very satisfactory, but during the amaranthus period the departures are greater. The evaporation equations for the several periods are as follows:

Rye period.....	$0.787 R_v + 0.292 D = E;$
Alfalfa period.....	$0.680 R_v + 0.360 D = E;$
Amaranthus period.....	$0.563 R_v + 0.411 D = E;$

in which E represents the evaporation expressed as a percentage of the maximum.

It will be observed that the radiation has a preponderating influence in each instance.

DISCUSSION OF LEAST-SQUARE REDUCTIONS

The least-square reductions again emphasize the fact that the transpiration response to changing environmental conditions is not the same for different plants. In other words, the distribution of the transpiration loss through the day varies with different plants. Furthermore, the distribution of the transpiration loss differs from the distribution of the evaporation loss from a shallow tank. As a whole, the agreement between observed and computed evaporation is much closer than between observed and computed transpiration. Either some factor operative in transpiration yet remains to be accounted for or the transpiration system changes its coefficient during the day. The latter condition may result from stomatal control or through the inability of the plant to secure sufficient water to maintain complete turgidity during the day. The fact that the evaporation on clear days can be satisfactorily accounted for from a consideration of radiation and saturation deficit indicates that the essential environmental factors have been considered and suggests that the outstanding differences between observed and computed trans-

piration are due to differences in the plants or to some change in the plant as the day progresses.

It is probable that plants differ also in their response to solar energy, the absorption coefficient of different plants not being the same, while the dissipation of the energy absorbed is quite different in different plants. In other words, the ratio of the energy dissipated through transpiration and lost by the plant through emissivity is not the same for all species. Such changes probably occur also in the same plant during the daily cycle, which would modify the transpiration coefficient irrespective of the changes in physical conditions.

SUMMARY

This paper deals with measurements of transpiration on clear days at Akron, Colo., in relation to environmental factors. The plants, which included wheat, oats, rye, sorghum, alfalfa, and amaranthus, were grown in large sealed pots of the type used in water-requirement measurements, containing sufficient soil (about 115 kgm.) to enable the plants to make a normal growth. The transpiration was determined by weighing, four automatic platform scales recording each 20-gm. loss being used for the purpose. Automatic records were simultaneously made of the radiation intensity, the air temperature, the depression of the wet-bulb thermometer, the evaporation, and the wind velocity. The radiation intensity and the wet-bulb depression were measured by differential telethermographs, and the evaporation rate from a free-water surface was determined by mounting a shallow, blackened evaporation tank 3 feet in diameter on an automatic platform scale.

Composite graphs are presented, showing the mean hourly transpiration rate for each of the plants considered, together with the mean hourly values of the radiation, air temperature, wet-bulb depression, and wind velocity for the transpiration period and also the mean hourly evaporation rate. On the basis of the form of the curves the transpiration graphs may be grouped into two classes having characteristic features. The cereals show a marked change in the slope of the transpiration graph in the forenoon unaccompanied by corresponding changes in the environmental factors. On the other hand, the forage plants and amaranthus give little or no indication of such a change. This flattening of the graphs in the case of the cereals appears to be due to some change in the plant, resulting in a reduction in the transpiration rate below what would be expected from the form of the curve during the early morning hours.

The hourly transpiration rate of the cereals on clear days increased steadily, though not uniformly, from sunrise to a maximum value, usually reached between 2 and 4 p. m., after which it fell rapidly to the night level. The transpiration graphs for sorghum, alfalfa, and amaranthus were somewhat more symmetrical with respect to midday, reaching

their maximum between noon and 2 p. m., after which they fell approximately with the radiation.

The transpiration during the night at Akron is very low, being only 1 to 5 per cent of the transpiration during the daylight hours.

The radiation graphs are practically symmetrical with respect to noon, showing that the days selected were relatively clear. When all the mean hourly values are expressed as a percentage of the maximum, the radiation intensity rises in advance of the transpiration (and in advance of all the other environmental factors as well) and falls either in advance of the transpiration or with it, depending on the plant considered. Radiation then may be looked upon as the primary causative factor in the cyclic changes.

The air temperature and wet-bulb depression graphs are very similar in form, since the latter can be determined from the former on days in which the absolute humidity of the air is not changing. The transpiration graphs usually rise and always fall in advance of air temperature.

The evaporation graph from the shallow, blackened tank (water approximately 1 cm. in depth) is similar in form to the graph representing the vertical component of radiation. This is to be expected, since only the vertical component would strike the horizontal water surface. The evaporation graph rises and falls with, or slightly later than, the vertical component of radiation.

Computation of the correlation coefficients between transpiration and the various environmental factors shows the radiation, air-temperature, and wet-bulb depression to be correlated with transpiration approximately to the same degree. The correlation coefficients of transpiration with radiation range from 0.82 to 0.89; with temperature from 0.77 to 0.86; and with wet-bulb depression, from 0.75 to 0.85. These figures show the intercorrelations existing among the environmental factors, since the sum of the squares of the coefficients of independent causative factors influencing transpiration can not exceed unity. If radiation is taken as the primary causative factor, the correlation coefficients show that 0.67 to 0.77 of the transpiration on clear days under Akron conditions is determined by the radiation intensity.

If the environmental factors are considered as independent, their relative influence on transpiration may be determined by the method of least squares. In the case of alfalfa and amaranthus, the vertical component of radiation and the temperature enter into the determination of transpiration in the ratio of 1 to 1, approximately; and the corresponding ratios for vertical radiation and saturation deficit are approximately the same. On the other hand, in the case of rye, the radiation by this method of reduction shows less influence than either temperature or saturation deficit on the transpiration rate, which from 9 a. m. to 2 p. m. shows a marked departure from the graph indicated by the transpiration during the early morning hours.

Least-square reductions of the dependence of transpiration upon radiation and air temperature or upon radiation and saturation deficit do not account entirely for the observed transpiration, although a satisfactory agreement between computed and observed evaporation is obtained by the use of these environmental factors. This indicates that the plant undergoes changes during the day which modify its transpiration coefficient. In other words, our results support the conclusion of other investigators that plants under conditions favoring high evaporation do not respond wholly as free evaporating systems, even if bountifully supplied with water and no visible wilting occurs.

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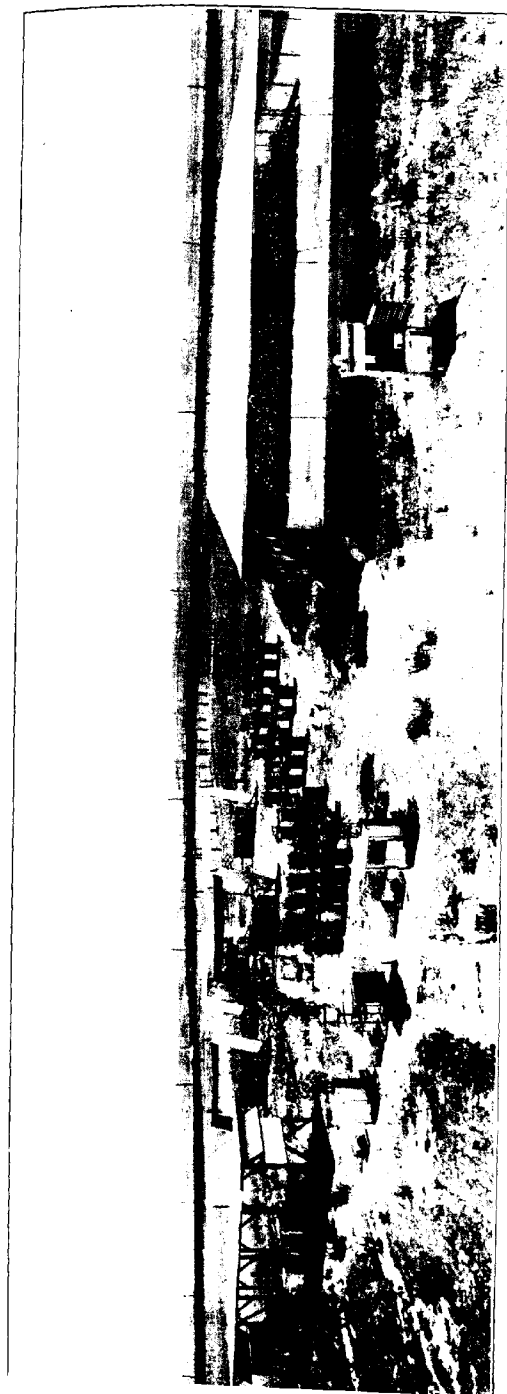
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PLATE LIII

General view of the water requirement and transpiration experiments at Akron, Colo., on July 8, 1913. The large, screened inclosure in which the transpiration measurements were made in 1912 is shown at the right. The small instrument shelter in the foreground contained differential thermographs for measuring wet-bulb depression and solar radiation. The glass envelope surrounding the bulb of the radiation instrument may be seen on the top of the instrument shelter. At the left in the foreground is shown balance A, the front of the box open, and the recording device uncovered at the left. This balance is carrying a pot of sunflower. The next balance, B, carries the evaporation tank; balance C, another sunflower pot; and balance D, under the shade at the left, a third sunflower pot. The exposure of balances A and B, as used in the 1913 and 1914 determinations, is shown in this illustration.

Hourly Transpiration Rate on Clear Days



Hourly Transpiration Rate on Clear Days

PLATE LIV

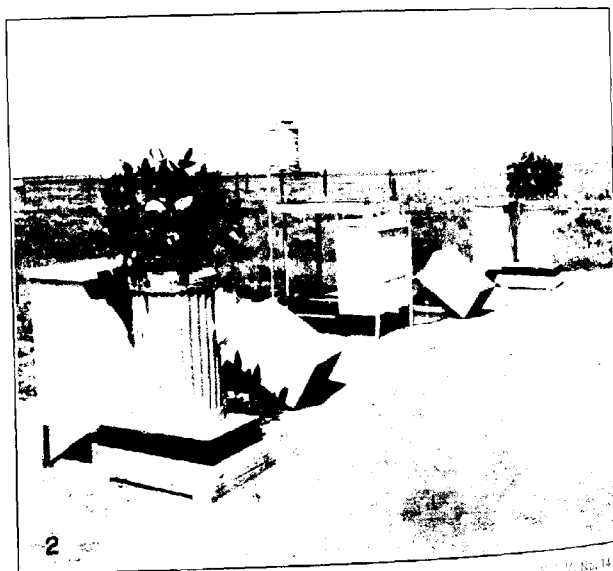
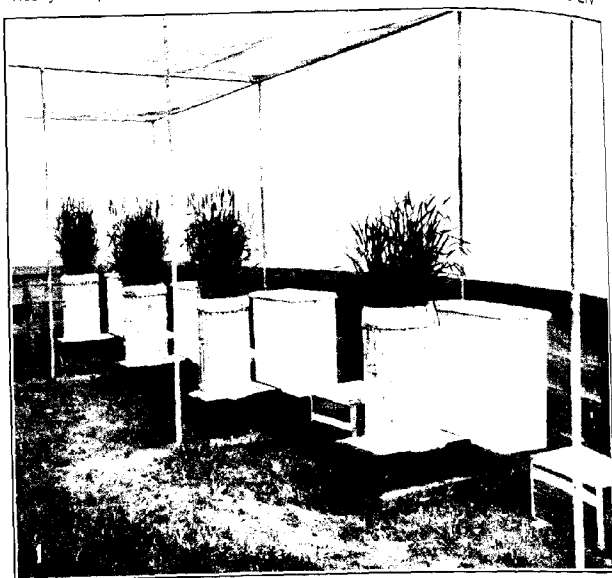


PLATE LIV

Fig. 1.—Wheat on automatic balances in the screened inclosure, July 3, 1912, showing the exposure and arrangement of the 1912 experiments.

Fig. 2.—Automatic balances A, B, and C; A and C carry pots of cowpea and B carries the evaporation tank. This shows the exposure of the plants in the 1913 and 1914 transpiration experiments.

PLATE LV

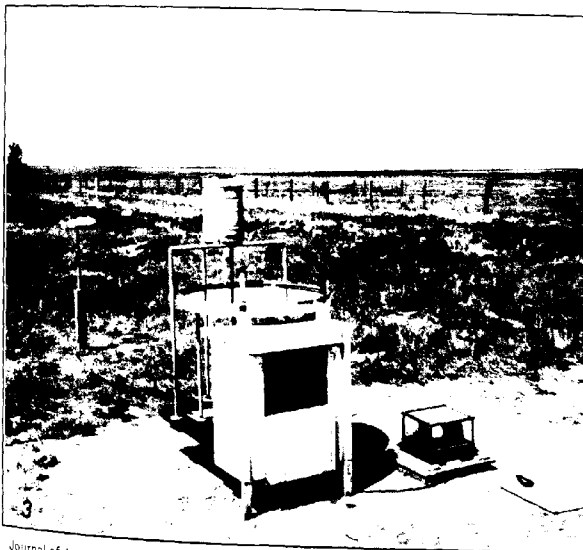
Fig. 1.—A pot of alfalfa showing the growth and size of plants used in the transpiration experiments. The pot is 26 inches high and 16 inches in diameter.

Fig. 2.—A pot of *Amaranthus retroflexus* of the type used in the transpiration measurements.

Fig. 3.—Evaporation tank mounted on automatic balance. The reservoir is shown above in the back. The tank has an area of 6,540 sq. cm. and the water is maintained at a depth of 1 cm. The balance recorder is shown at the right and the anemometer at the left in the background.

Hourly Transpiration Rate on Clear Days

PLATE LV



EFFECT OF NATURAL LOW TEMPERATURE ON CERTAIN FUNGI AND BACTERIA

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The effect of the very intense cold of northern winters on the life and viability of fungi and bacteria does not seem to have been tested extensively, yet its importance in checking the spread of plant infections from these sources would appear to be very great.

Wolf¹ has shown that certain parasitic and saprophytic fungi remain present and alive in Nebraska orchards during autumn, winter, and spring. The majority of the species are saprophytic, the more common ones being *Alternaria* spp., *Cladosporium* spp., and *Penicillium expansum*. Only one parasite, the cause of leafspot, was present in abundance regardless of temperature. He found more spores in the air in neglected orchards than in well-cared-for ones and also found them to be much more abundant everywhere than commonly has been supposed. All his determinations were made by exposing plates at various places in the orchard and then carefully studying and determining the colonies after they had developed.

In the present study certain known fungi and bacteria were exposed in pure cultures to the low temperature of the winter months. The organisms were started upon nutrient agar in test tubes—i. e., allowed to grow at laboratory temperature for about one week after inoculation—and then these cultures were placed in a corner where there was a free circulation of air, but where they were protected from the rain and snow.

The tubes were inoculated between December 10 and 16 and were exposed in the outhouse on December 21, with the exception of *Actinomyces organicus*, which was not exposed until December 31. The cultures were undisturbed throughout the winter, during which time a minimum temperature of -24° C. was reached. The medium did not dry up to any extent, but was rather moist when brought into the laboratory, as the frequent freezings and thawings seemed to impair the solidifying power of the agar.

On April 14 the cultures were brought into the laboratory and tested immediately for vitality. This was done by transferring part of the exposed culture to fresh nutrient-agar slants and allowing the new inoculations to grow at room temperature. In all cases except one the response to fresh agar was soon evident, but in the case of *Actinomyces*

¹ Wolf, F. A. The prevalence of certain parasitic and saprophytic fungi in orchards, as determined by plate cultures. *In Plant World*, v. 13, no. 7, p. 164-172, fig. 1; no. 8, p. 196-201, fig. 2-5. 1910.

chromogenus the organism was probably killed by the low temperature. A large proportion of the conidia of both strains of *Sclerotinia cinerea* were found to be capable of germination. Table I gives the organisms and materials used and the results obtained.

TABLE I.—Results of tests for vitality of various organisms after exposure to low temperatures (1912-13)

Organism.	Medium.	Response of the mycelium.
<i>Cephalothecium roseum</i>	Synthetic agar..	Excellent growth in 2 days, with production of spores.
<i>Sclerotinia cinerea</i> (Vermont culture).....	.....do.....	Excellent growth in 36 hours; many conidia produced.
<i>Alternaria solani</i>	Lima-bean agar..	Good growth after 2 days.
<i>Cylindrosporium pomi</i>	Synthetic agar..	Good growth after 6 days; slow to start.
<i>Sphaeropsis malorum</i>.....	.....do.....	Slow growing at first; very good later.
<i>Fusarium</i> sp. of conifers.....	.....do.....	Excellent growth in 5 days over entire slant. Two trials needed to get results.
<i>Glomerella rufomaculans</i>.....	.....do.....	Started after 1 day and grew quickly.
<i>Sclerotinia cinerea</i> (culture from New Jersey Experiment Station).....	.....do.....	Very good growth in 5 days.
<i>Plowrightia morbosa</i>.....	.....do.....	Excellent growth after 1 day.
<i>Venturia inequalis</i>.....	.....do.....	Good growth in 5 days with fruiting. Two trials necessary to get results.
<i>Actinomyces organicus</i>	Plain agar.....	Good growth in 2 tubes in 6 days.
<i>Actinomyces chromogenus</i>.....	.....do.....	No growth after a month. No growth on second trial.

The results secured during the winter of 1912-13 were so encouraging that further trials were made the following winter. Several organisms not tested previously were exposed with those first used, and the varieties used the first winter were tested on different media.

Since organisms in nature would be necessarily in a dry state during the winter and without much, if any, nourishment, it was the aim of the author to imitate for his pure cultures these conditions so far as possible. Accordingly, dry cultures of the various fungi chosen for this work, as well as the cultures on nutrient media, were exposed during the winter of 1913-14. These dry cultures were made by removing the growth of the fungus from the surface of the agar with a sterile needle and placing it in an empty, plugged, sterile test tube. A little of the agar was necessarily carried over with the fungus, but not enough to supply it with moisture or food for any length of time. In the case of the bacteria, some of the material from an agar slant was swabbed out with pieces of sterile cotton and placed in plugged, sterile test tubes. All of the cultures thus transferred were dried for 10 days in a warm closet in the laboratory before being exposed. It was expected that the question of food could be practically eliminated, while moisture was available only as it was carried by the air to the cultures.

The cultures were all prepared earlier the second season, and they were placed in the same corncrib on December 13, 1913. Along with the cultures was placed a Draper self-registering thermometer, in order that a comparative record might be kept of the temperatures to which the organisms would be exposed. This thermometer did not register accurately below -27°C ., so that during the three periods when the tempera-

ture fell below that point the official records of the Weather Bureau were considered as applicable to this test. The temperature was recorded from the date of exposure to March 1, 1914.

Table II summarizes briefly the extremes of temperature in the corncrib and also gives the lowest official record during each week of exposure.

TABLE II.—Temperature records at Burlington, Vt., during winter of 1913-14

Date.	Range in corncrib.	Lowest official record.
	°C.	°C.
Dec. 12-19, 1913.....	7 to -13	-14
Dec. 19-26, 1913.....	4.5 to -9	-9.4
Dec. 26, 1913-Jan. 2, 1914.....	-4.5 to -23	a -24.4
Jan. 2-9, 1914.....	0 to -19	-20.5
Jan. 9-16, 1914.....	2 to -29	b -32
Jan. 16-23, 1914.....	-4 to -22.8	-23.3
Jan. 23-30, 1914.....	7 to -20.5	-22
Jan. 30-Feb. 6, 1914.....	4.5 to -14	.....
Feb. 6-13, 1914.....	2.8 to -26.6	c -30
Feb. 13-20, 1914.....	-4 to -26	d -27.7
Feb. 20-28, 1914.....	10 to -23.3	e -25

a Jan. 1.

b Jan. 14.

c Feb. 12.

d Feb. 16.

e Feb. 25.

Tests were made of the vitality of the cultures on January 17, February 21, and March 27. These tests were made by transferring some of the growth from duplicate tubes of all the exposed cultures to fresh media of corresponding kind and holding at room temperature (19 to 22° C.) for several days. An abundance of tubes had been prepared, so that when the transfers showed no growth at the end of seven days two more exposed tubes could be brought in and tested. It will be noted that the first test for vitality was made on January 17, immediately following the extremely cold weather of January 13 and 14, when the official record was -30° and -32° C., respectively. Many of the organisms had withstood temperatures of -24° the previous winter, so it was not thought necessary to test any of them until they had experienced more severe cold. In Table III the results of these tests are summarized. Each sign used indicates the response of one culture; the plus (+) signs indicate growth, and the minus (-) signs mean that the culture was dead; "c" denotes contamination of the culture.

TABLE III.—Results of tests for vitality of various organisms after exposure to low temperatures (1913-14)

Organism.	Medium.	Jan.		Feb.		Mar.		Apr.	
		Date.	Result.	Date.	Result.	Date.	Result.	Date.	Result.
<i>Siderothrix cinerea</i>	Synthetic agar.....	17	++	21	++	27	++	13	++
	Dry synthetic agar.....	17	++	21	++	27	++	13	++
<i>Alternaria solani</i>	Synthetic agar.....	17	++	21	++	27	++	13	++
	Dry synthetic agar.....	17	++	21	++	27	++	13	++
	Lima-bean agar.....	17	++	21	++	27	++	13	++
<i>Cylindrosporium pomi</i>	Synthetic agar.....	17	++	24	++	27	++	13	++
	Dry synthetic agar.....	17	++	24	++	27	++	13	++
<i>Sphaeropsis malorum</i>	Synthetic agar.....	17	++	24	++	27	++	13	++
	Dry synthetic agar.....	17	++	24	++	27	++	13	++
<i>Fusarium</i> sp. of conifers.....	Synthetic agar.....	17	++	24	++	27	++	13	++
	Dry synthetic agar.....	17	++	24	++	27	++	13	++
<i>Gomelleria fumigulans</i>	Synthetic agar.....	17	++	21	++	27	++	13	++
	Dry synthetic agar.....	17	++	21	++	27	++	13	++
<i>Phaeocephala morbosa</i>	Synthetic agar.....	17	++	21	++	27	++	13	++
	Dry synthetic agar.....	17	++	21	++	27	++	13	++
<i>Venturia inaequalis</i>	Synthetic agar.....	17	++	24	++	27	++	13	++
	Dry synthetic agar.....	17	++	24	++	27	++	13	++
<i>Cephalothecium roseum</i>	Synthetic agar.....	17	++	21	++	27	++	13	++
	Dry synthetic agar.....	17	++	21	++	27	++	13	++
<i>Colletotrichum Lindemuthianum</i>	Synthetic agar.....	17	++	21	++	27	++	13	++
	Dry synthetic agar.....	17	++	21	++	27	++	13	++
<i>Atrochaete cedrella</i>	Synthetic agar.....	17	++	21	++	27	++	13	++
	Dry synthetic agar.....	17	++	21	++	27	++	13	++
<i>Phytophthora cinnamomi</i>	Synthetic agar.....	17	++	24	++	27	++	14	++
	Dry synthetic agar.....	17	++	24	++	27	++	14	++
<i>Pseudomonas campestris</i>	Lima-bean agar.....	17	++	24	++	27	++	14	++
	Dry Lima-bean agar.....	17	++	24	++	27	++	14	++
<i>Bacillus melanis</i>	Plain-agar slants.....	17	++	28	++	30	++	15	++
	Plain-agar slants.....	17	++	28	++	30	++	15	++
<i>Aspergillus chromogenuus</i> (<i>Oospora cecid-</i> <i>ites</i>).....	Dry cotton wads.....	17	++	30	++	30	++	16	++
	Plain-agar slants.....	17	++	30	++	30	++	16	++
<i>Aspergillus benii</i>	Dry cotton wads.....	17	++	30	++	30	++	16	++
	Plain-agar slants.....	17	++	30	++	30	++	16	++
<i>Bacillus licheniformis</i>	Plain-agar slants.....	17	++	30	++	30	++	16	++
	Dry cotton wads.....	17	++	30	++	30	++	16	++

If the results of the exposures of these organisms to low temperature are summarized, it will be noted that five fungi, *Sclerotinia cinerea*, *Cephalothecium roseum*, *Glomerella rufo-maculans*, *Venturia inequalis*, and *Ascochyta colorata*, lived over winter under all conditions of exposure; while four others, *Alternaria solani*, *Cylindrosporium pomi*, *Plowrightia morbosa*, and *Phytophthora omnivora*, lived over on some media but not on others. One fungus, *Fusarium* sp. of conifers, succumbed to the low temperature, while two others, *Colletotrichum Lindemuthianum* and *Sphaeropsis malorum*, were so weak that only under very favorable conditions would they respond to fresh media. Only two of the six kinds of bacteria exposed can be safely said to have survived—*Bacillus melonis* and *Actinomyces chromogenus*. Transfers from exposed cultures of *B. melonis* were found to agree in all distinctive characters with those given by Giddings. It is to be noted that this organism forms no spores. The growth of transfers from exposed cultures of *Actinomyces chromogenus* was very characteristic and hardly mistakable for any other organism. In regard to the other bacterial cultures, it may be said that they were more or less contaminated during the exposure; and although some of the transfers from them resemble the original growth, this was not well enough marked to prevent all suspicion. On the whole, the various organisms seem to withstand exposure better in a dry condition than when food and moisture are present.

Thinking that some of the organisms might die from natural causes other than the exposure to low temperature, the author retained part of the culture made for this test indoors as a check. They were kept in a cool room (14 to 20° C.) throughout the winter and tested for vitality late in March, 1914. In practically every case these cultures were living at that time, and no organism given in Table III can be said to have died otherwise than by exposure to low temperature.

No entirely satisfactory explanation has been offered as yet of the changes which take place in fungi and bacteria during or after exposure to extreme cold. The results obtained by the author throw little or no light on the manner of the freezing nor on the subsequent death. The present work is a record of the fact that certain fungi and bacteria are able to withstand extreme cold, while others succumb to it, but does not attempt to advance any theory as to the internal changes which contribute to the weakening or death of the organisms thus tested.

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